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Future of the American City

THE CASE OF CAPE ANN

Study 3: Waste Recovery

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Harvard University
Graduate School of Design

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Cape Ann

The Case of Cape Ann: Compound Vulnerabilities is led by Kira Clingen and Charles Waldheim with essential contributions by Celina Abba, Christopher Ball, Aziz Barbar, Fabiana Casale, Charlie Gaillard, Raveena John, Slide Kelly, Angela Moreno-Long, Nono Martinez Alonso, and Arty Vartanyan. The project is advised by Jill Desimini, Gareth Doherty, Rosetta Elkin, Andrew Fox, Jerold Kayden, Jesse Keenan, David Moreno Mateos, Rick Peiser, Chris Reed, Maggie Tsang, and Amy Whitesides. The project is informed by collaborations with the Harvard GSD Critical Landscapes Design Lab, the Woods Hole Group, NOAA, and Limnotech, and is made possible by the generous support of the Cape Ann Climate Coalition, the Gloucester Meetinghouse Foundation, Manchester-by-the-Sea, and the City of Gloucester.

Methodology

Scenario planning is a method of long-term strategic planning that creates representations of multiple, plausible futures used to inform decision-making in the present. While complementary to probabilistic models that forecast future vulnerabilities, scenario-based planning shifts emphasis from statistical probability to ways of thinking about the future.

The goal of scenario planning is not to predict the most likely outcome but to reveal biases and blind spots in complex and non-linear situations. Scenario planning is particularly effective in grappling with climate change, which is beyond the control of a single individual, institution, or community and entails high degrees of uncertainty. For this reason, scenario planning is among the primary methodologies used by the Intergovernmental Panel on Climate Change (IPCC) and other leading institutions focused on climate change. These scenarios approach the effects of climate change and adaptation measures at a regional scale, and also address issues that are relevant to each municipality. By reframing the issue of climate adaptation on Cape Ann through one possible outcome among many, this work is intended to support stakeholders as they make decisions in the present.

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Waste Recovery

The current solid waste disposal and wastewater treatment practices on Cape Ann are unsustainable. Study 3: Waste Recovery proposes introducing new technologies to reduce the emissions of greenhouse gases generated by the decomposition of solid waste. The study proposes strategies to meet the 2050 goals of the Massachusetts waste reduction plan by aggregating the region's waste collection practices, expanding its recycling and reuse programs, and introducing waste to energy technologies.

Converting waste into energy is particularly prescient because New England is largely dependent on natural gas for power generation and heating. These resources rely on aging infrastructure. ISO New England has estimated that there could be fuel shortages and electrical system reliability issues by 2024 due to regional fuel security concerns. It is therefore important that the Cape Ann region increase its energy independence. Waste to energy technologies can help to offset the 12,931,108 Therms of natural gas that Cape Ann uses annually.

The study envisions multiple strategies to convert waste streams, including wastewater, sewage sludge, and solid waste, into viable low-carbon fuel economies. The study focuses on the critical need to relocate the West Gloucester and Manchester-by-the-Sea Wastewater Treatment Plants away from low-lying coastal areas at risk of damage during an extreme storm event.

Case Studies

Solid waste and wastewater treatment plants are critical municipal infrastructures. Waste-to-energy facilities employ a range of technologies to convert municipal solid waste into energy, and are already a part of energy conversion strategies around the globe. It is critical to carefully evaluate the design, site planning, and types of community engagement that these facilities employ in addition to the technologies they are pioneering.

Municipal Curbside Composting in Hamilton and Wenham

LOCATION
Hamilton and Wenham, Massachusetts, United States

COSTS
N/A

SAVINGS
$40,000/year

AMOUNT
342 tons/year

POPULATION
13,000

TECHNOLOGIES
Curbside organics pickup

CONSTRAINTS
Public support, education and outreach

The towns of Hamilton and Wenham were the first municipalities in New England to offer year-round curbside organics collection for composting.[1] After citizens' organizing efforts and a successful pilot, the towns launched their composting program for all residents in 2012. In November 2020, Hamilton issued the first mandate to compost food waste in Massachusetts.[2] Organics make up 25% of the towns' waste; if not diverted to the composting facility, these organics are incinerated at a North Andover waste facility.[3] There is, therefore, high potential for both waste diversion and the prevention of greenhouse gas emissions.

The composting program was largely citizen-driven. In 2009, the Hamilton-Wenham League of Women Voters demonstrated the benefits of pay-as-you-throw for encouraging recycling, which led to its implementation and an increase in recycling rates of both towns.[4] The success of this program inspired the Hamilton Recycling Committee to conduct a seventy-five-household demonstration with the support of Brick Ends Farm Composting and New England Solid Waste haulers, both of whom waived their fees for the program.[5] This led to a year-long, 675-household pilot project in 2010, the success of which led to the enaction of the towns' comprehensive and ongoing composting program in 2012.[6]

In the first year of the program, Hamilton collected 229 tons of organics, saving over $25,000 in tipping fees, and Wenham collected 113 tons, saving over $15,000.[7] The success of this program inspired nearby Ipswich, Salem, and Manchester-by-the-Sea to launch municipal composting programs.[8] As of 2013, Hamilton was studying the placement of an anaerobic digestor on a capped landfill as a method of food waste diversion to generate energy.[9]

Massachusetts Municipal Association, "Composting bins," 2021.

Key to the initial and ongoing success of this composting program is the involvement of citizen volunteers, education and outreach, and willing local partners. In addition to organizing the pilot program, volunteers ran a hotline to answer questions and respond to complaints, which brought more people on board without overwhelming public works staff.[10] Ongoing education about proper organics disposal practices helps procure high-quality waste for Brick Ends Farm to process.[11] The Farm offers tipping fees at significantly lower cost than the Andover waste facility and the hauling company purchased a split truck to pick up recyclables and organics simultaneously, making composting an easy and attractive alternative for waste disposal.[12]

John Sweeney, "Composting facility," 2014.

Greater Lawrence Sanitary District

LOCATION
North Andover, Massachusetts, United States

COSTS
$27 million - combined heat and power project

SAVINGS
$3 million/year

CAPACITY
70 MGD

AVERAGE
30 MGD

POPULATION
250,000

TECHNOLOGIES
Anaerobic co-digestion, combined heat and power

CONSTRAINTS
Sources of food waste, quality of organics

The Greater Lawrence Sanitary District (GLSD) operates a net-zero wastewater treatment plant that serves the populations of Lawrence, Methuen, Andover, North Andover, and Dracut, in Massachusetts, as well as Salem, NH. In addition to wastewater treatment, the plant adds food waste to its anaerobic digestion process, diverting organic waste from landfills and generating usable biogas. The GLSD to launched the Organics-to-Energy project in 2019 to include energy recovery in the disposal of organic materials. This project keeps organic material out of landfills and incinerators, which is a goal of the Massachusetts Department of Environmental Protection's 2020 Solid Waste Master Plan.[13]

The Organics-to-Energy project included $27 million for plant renovation and expansion activities, including adding an anaerobic digester, installing two combined heat and power engines, and expanding capacity for co-digestion of food waste.[14 15] About a third of the project was funded through grants and other state and federal programs, including the Clean Water Trust, MassDEP, Mass Clean Energy Center, the Department of Energy Resources, and the CHP Incentive Program from National Grid.[16] Commercial and residential food waste is collected at the Charlestown Waste Management CORe, where it is processed before being sent to the North Andover plant.[17] The anaerobic digestion processes use the combined sewage and food waste to produce biogas (about three times as much as was produced without the food waste) as well as biosolids, which are turned into fertilizer pellets.[18]

CDM Smith, "Aerial view of Greater Lawrence Sanitary District," 2018.

The GLSD completed the plant expansion in December 2019 and the project was rebranded as Project Net-Zero.[19] Through the co-digestion of food waste in the expanded anaerobic digesters and the conversion of energy with the combined heat and power system, GLSD has been able to produce as much electricity as is needed for operating the wastewater treatment plant and the nearby Riverside Pumping Station.[20] Since 2021, the plant has produced more energy than it uses—approximately 70,000 kilowatt hours (kWh) per day—and reduced its greenhouse gas emissions by 20%.[21] On-site energy production also allows the plant to operate when the grid is experiencing blackouts or brownouts, providing uninterrupted service during emergencies.[22]

GSLD, “GSLD,” 2018.

Lake Whitney Water Treatment Facility

LOCATION
New Haven, Connecticut, United States

COSTS
$60 million, including $5/ft^2 landscaping

CAPACITY
55 MGD

AVERAGE
15 MGD

POPULATION
130,000

TECHNOLOGIES
Green roof, geothermal heating and cooling, water purification, charcoal filtration, gravity-fed water treatment

CONSTRAINTS
Community use

The Lake Whitney Water Treatment Facility was designed by architect Steven Holl to integrate education, architecture and landscape design on a water treatment facility site. The plant performs the required functions of any water treatment facility: removing undesirable chemicals, biological contaminants, suspended solids, and gases from contaminated water to produce drinking water. In addition, the project serves as a model for public infrastructure where people can interact directly with the facility, and use the landscape in their everyday lives.

The project was realized as a collaboration between the South Central Connecticut Regional Water Authority, Steven Holl, structural and bioengineers, landscape architecture firm MVVA, and civil engineers.[23]

Neighbors along the lake were concerned with walking the 14-acre grounds of the plant, and were consulted directly in the development of the design, including implementing a series of footpaths for the community. A group of thirteen residents were chosen to form a design committee for the open space in addition to the water purification requirements.

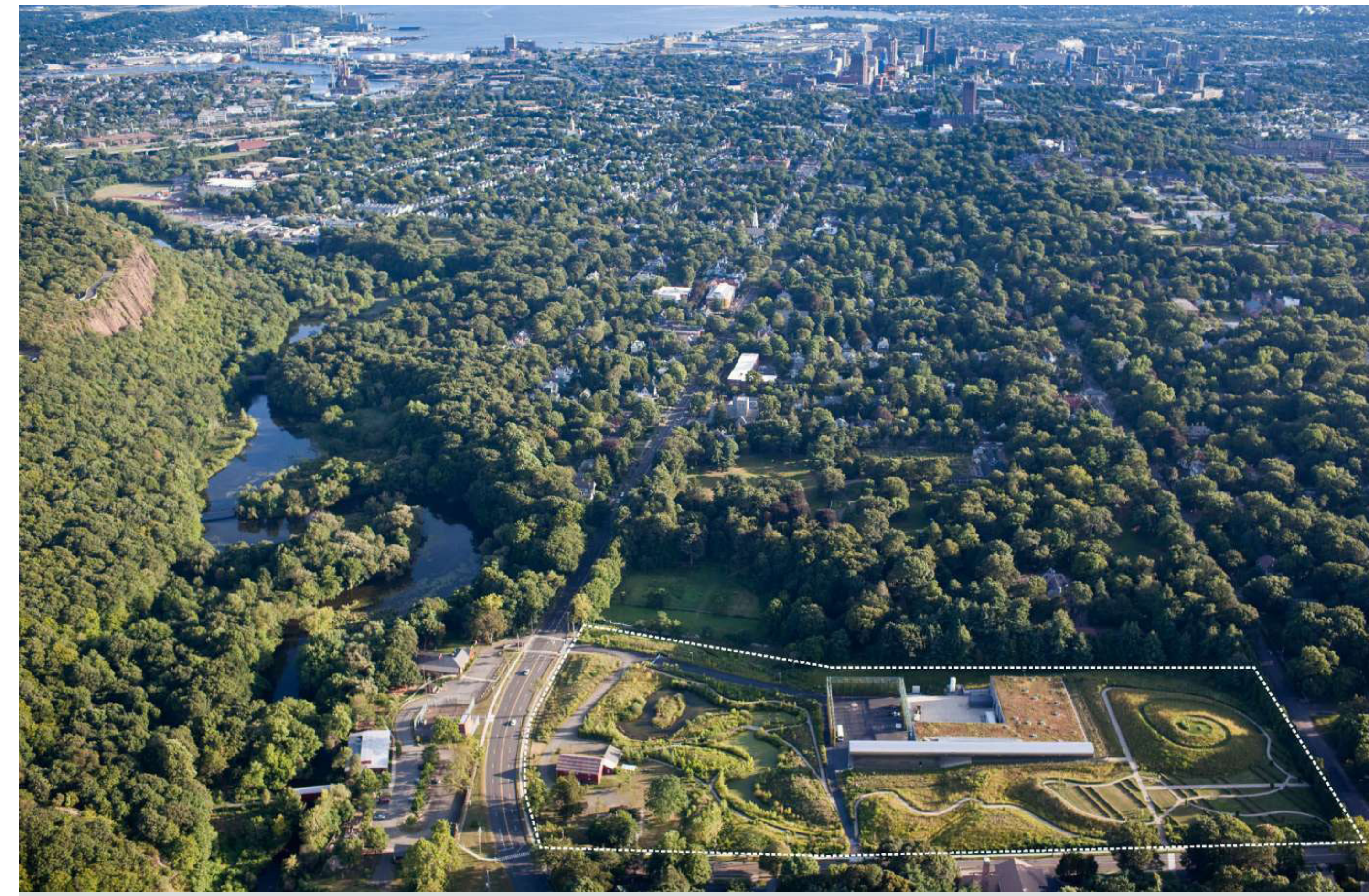
Three-quarters of the buildings are underground, underneath the largest green roof in Connecticut. This design allows for gravity driven filtration and treatment thorugh a six-step process. Administration offices, laboratories, multipurpose rooms and a public lecture hall are all housed in a 360- foot structure above ground. The building itself is made of recycled materials, including cork, tree bark and recycled glass-chips. The building uses natural ventilation and daylighting to reduce energy consumption.

MVVA, “Lake Whitney Water Treatment Facility,” 2005.

Lake Whitney Water Treatment Facility

The treatment plant replaced a 1906-era plant and provides 15 million gallons of water a day to 12 towns. The property includes a public park and educational facility, which expands the existing wetland area where the site was originally located. The design of the project is a microcosm of the New England watershed, with swales guiding water runoff through discrete landscape types, including farmland, meadow and valley streams, before collecting it in a new pond to recharge the groundwater table underneath the park. Earth excavated on site was reused to create the topography of the landscape, and the planting design was inspired by restoration ecology.

The landscape design strategy was developed as a partnership between MVVA, the Connecticut Department of Environmental Protection, the U.S. Army Corp of Engineers, and the Inland Wetland Committee.[24]



MVVA, "Lake Whitney Water Treatment Facility Connection to Surrounding Region," 2005.

EBMUD Wastewater Treatment Plant, Oakland, CA

LOCATION
Oakland, California, United States

COSTS
$13 million/4.5 MW turbine

SAVINGS
$3 million/year

CAPACITY
168 MGD

AVERAGE
63 MGD

POPULATION
740,000

TECHNOLOGIES
Anaerobic co-digestion, low-emission turbine

CONSTRAINTS
Energy conversion capacity, sources of food waste

The East Bay Municipal Utility District (EBMUD) in Oakland, California, is a wastewater treatment plant on the forefront of electricity generation and solid waste management. It is the first large-scale wastewater treatment plant in North America to use anaerobic co-digestion. It is also the first plant in the United States to generate more energy than is needed for on-site operations.[25][26] Its success is due in large part to EBMUD's innovative practices and adaptability; the plant frequently adjusts its processes to respond to regional opportunities and demands.

The plant first started using biogas to generate electricity in 1985 with three 2.1-megawatt (MW) engines.[27] At that time, Oakland's industrial sector provided EBMUD with large quantities of wastewater saturated with high levels of biochemical oxygen demand. This waste had high potential for biogas generation.[28] With the shift in Oakland's land use from industrial to residential, that potential decreased and EBMUD was forced to reconsider their electricity generation methods.

In 2002, EBMUD began adding fats, oil, grease, and food waste to the existing anaerobic digesters as part of a Resource Recovery program.[29] The food waste is sourced locally from nearby restaurants, grocery stores, and markets, where food scraps are separated from other solid waste.[30] Wineries, poultry farms, and other industries in the area also send their organic waste to EBMUD.[31] The plant receives between twenty and forty tons of food waste per day.[32] EBMUD is open 24 hours a day to receive waste brought to the site by a permitted supplier, such as a winery, or an approved hauler bringing waste on behalf of a supplier.[33] The Resource Recovery program increased the organic content of the wastewater, which thereby increased the facility's biogas production for onsite use. The amount of biogas produced by co-digestion would sometimes

Justin Sullivan, "EBMUD Wastewater Treatment Plant," 2021.

exceed the plant's capacity to generate electricity, so the excess methane would have to be burnt off.[34]

EBMUD installed a high-efficiency, 4.5 MW gas turbine in 2011, increasing the plant's generative capacity to 10 MW.[35] By 2012, the plant was generating more energy than it consumed and since then has consistently exported electricity to the grid.[36 37] Electricity sales have brought in approximately $500,000 annually. The plant is estimated to save $2.5 million per year by generating its own electricity.[38]

The success of the plant's approach is closely related to its particular location and the surrounding regulatory environment: the Bay Area is densely populated with many sources of high-quality food waste and California offers the utility district flexibility in its sustainability approaches.[39] In addition, the density of the region makes the treatment plant an attractive location in which to dispose of food waste, which otherwise goes to landfills or is hauled long distances for composting.[40 41] The use of food waste and the installation of a large, efficient turbine enables EBMUD to further the region's goals of waste reduction and energy production simultaneously.

Overaa, "EBMUD energy plant," 2020.

Digeponics at The Magic Factory

LOCATION
Tönsberg, Norway

AMOUNT
110,000 tons/year

TECHNOLOGIES
Anaerobic digestion, combined heat and power, vermicompost, insulated greenhouse

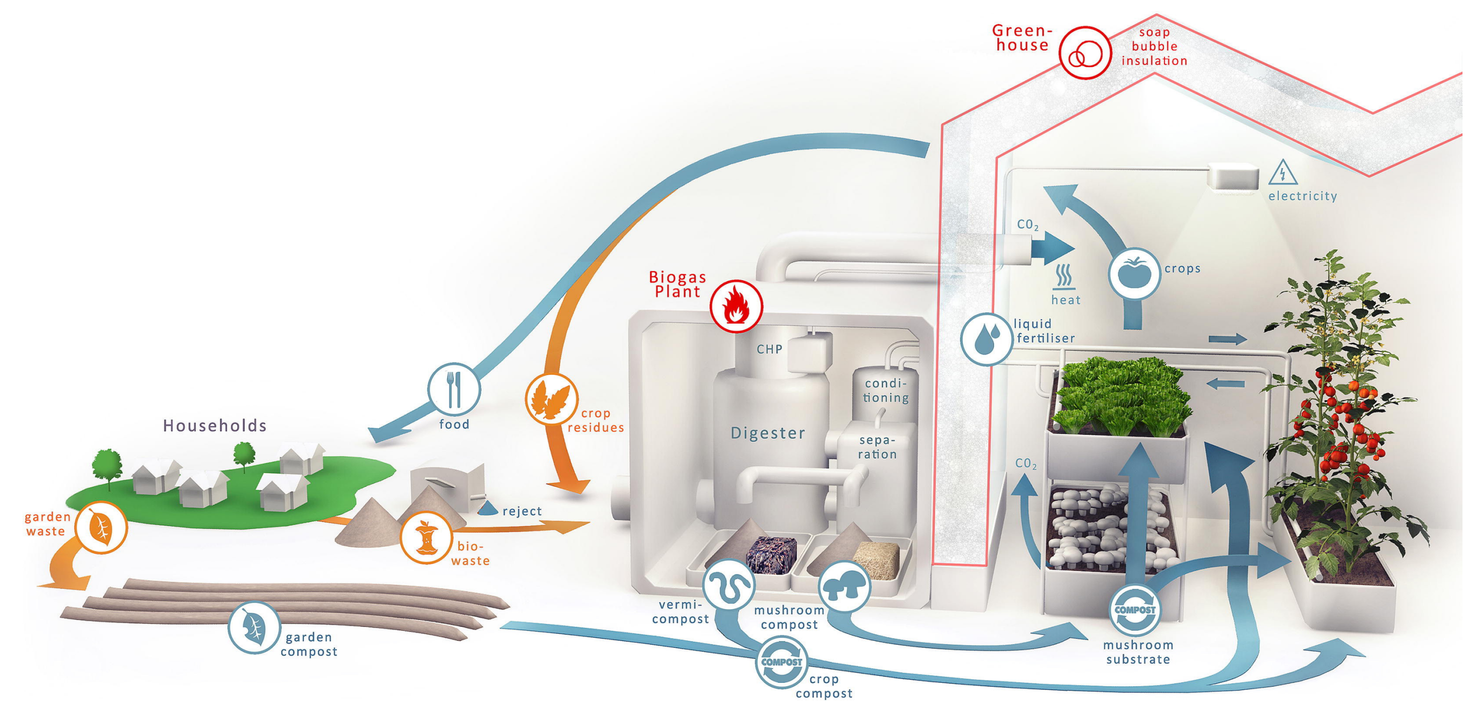
CONSTRAINTS
Quality of digestate, energy efficiency

This pilot project at the Magic Factory, a biogas facility in Tönsberg, Norway, successfully demonstrated the potential of growing food with the energy and nutrients recovered in the anaerobic digestion of food waste. Circular approaches to waste treatment are not new for this area. The Drammen municipal waste department was privatized in 2001 to focus on the market for waste products.[42] Lindum, the company, opened a biogas plant in 2015 to convert food waste and animal manure into biomethane for use by the regional buses.[43]

Lindum partnered with a greenhouse technology company, a regional waste company, and University of Life Sciences in Poznan to pilot the Food 2 Waste 2 Food project.[44] This project demonstrated a closed cycle of organic waste, energy production, and agriculture.[45] Food waste from commercial and residential sources went through anaerobic digestion, becoming biogas and digestate.[46] A combined heat and power generator combusted the biogas, turning the methane into carbon dioxide, which was then released into the adjacent greenhouse for plant growth.[47] The digestate was dewatered to separate the liquids and solids, which were used for irrigation, fertilizer, and vermicompost.[48] The greenhouse for the project was a novel structure, with soap bubbles used for insulation.[49]

Stoknes, “Greenhouse at The Magic Factory,” 2017.

The use of digestate in food production is what gives this method the name "digeponics."[50] This pilot shows great potential as a circular approach to agriculture and food waste. With efficient technology and careful treatment of organics and digestate, the local production of food using nearby sources of energy and nutrients seems possible. This method is being scaled up and commercialized in Poznan, Poland.[51] Given the high energy expenditure of food production and transport, the prevalence of food waste, and the carbon demand of traditional methods of organics disposal, the closed approach demonstrated here may provide an answer to some of the interconnected challenges facing the food and energy industries.[52]



Stoknes, "Diagram of digeponics processes," 2016.

Enerkem Alberta Biofuels Facility

LOCATION
Edmonton, Alberta, Canada

COSTS
$75 million, $127/ton tipping

CAPACITY
100,000 tons/year

OUTPUT
10 million gallons/year

POPULATION
980,000

TECHNOLOGIES
Syngas waste conversion

CONSTRAINTS
Market for products, space and capital for plant installation

The Waste to Biofuels and Chemicals facility in Edmonton, Alberta is the first commercial-scale facility to transform municipal solid waste into biofuels and other useful chemicals.[53] The company Enerkem pioneered this technology at a smaller scale project in Westbury, Québec, producing ethanol at a small scale in 2012.[54] The city of Edmonton has ambitious waste diversion goals and approached Enerkem about developing a large-scale waste-to-biofuels facility in service of these goals.[55] The Edmonton facility was built in 2013, though its commercial production of biomethanol only reached the anticipated scale in 2015.[56][57] Enerkem installed equipment to produce ethanol in 2017, diversifying its output.[58] The company is currently researching the production of high-quality fuel for heavy transportation equipment that can be sold through Canada's existing fuel infrastructure.[59]

This conversion technology uses any municipal solid waste that is not recyclable, organic, or metal.[60] Once those materials have been removed, the remaining waste is sorted and shredded, then converted into synthetic gas, called "syngas," in a gasifier.[61] The syngas is refined and purified then catalytically converted into biofuel (methanol and ethanol) and high-grade syngas that can be transformed into other products, such as plastics.[62] Enerkem sells these products to a variety of partners. The ethanol produced at the facility was approved in 2017 by the United States' Environmental Protection Agency (EPA)—the first waste-to-biofuel approval under the U.S. Renewable Fuel Standard.[63]

City of Edmonton, "Enerkem biofuels facility," 2017.

Though the process is expensive, with tipping fees at $127 per ton (compared to sending waste to a landfill at $111 per ton), Edmonton's need to divert waste and reduce greenhouse gas emissions made this ongoing cost worth the benefits.[64] This method complements existing recycling and composting practices as it only processes residual material, reducing only what is sent to the landfill. It therefore avoids disrupting the city's other waste reclamation approaches.[65] As of 2020, this conversion technology diverts 30% of Edmonton's waste that would otherwise be sent to landfills.[66]

BBA Consultants, "Aerial view of Enerkem facility," 2016.

Hydrothermal Processing Pilot System (HYPOWERS)

LOCATION
Central Contra Costa Sanitary District, Martinez, California, USA

COSTS
$2.4 million

SAVINGS
In development

CAPACITY
4035 GD

AVERAGE
4035 GD

POPULATION
45,000

TECHNOLOGIES
Hydrothermal processing, improved efficiency, power generation, sludge disposal

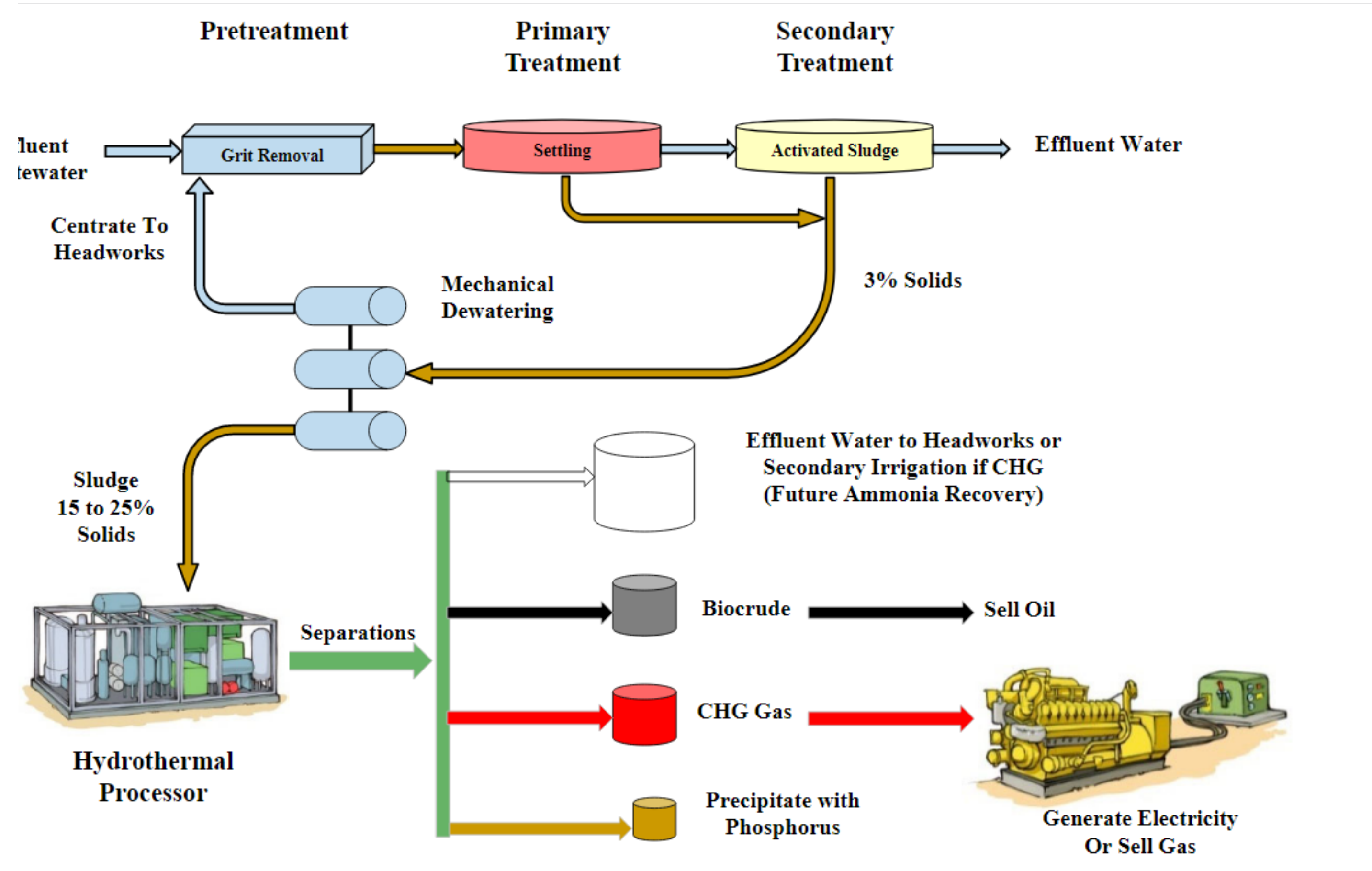
CONSTRAINTS
Land availability, scaling, technology development, funding

Wastewater contains five to ten times the amount of energy needed for the wastewater treatment process. Hydrothermal processing converts some of these energy intensive wet organic materials into biocrude oil and methane gas. The technology was developed at the Pacific Northwest National Laboratory through a partnership with the Water Research Foundation.

The HYPOWERS pilot system converts wastewater solids from a water resource recovery facility at subcritical temperatures and pressures them into biocrude oil and natural gas in less than an hour. This gas can be used in the same way as fossil natural gas. All wastewater solids are eliminated, and the facility is integrated into the existing wastewater treatment plant.

The pilot study is located in Central Contra Costa Sanitary District in Martinez, California, and handles a wastewater flow equivalent to a population of 45,000 people, roughly the size of the Cape Ann population. This includes 5,200 wet metric tons of sewage sludge per year, producing 390,000 liters of biocrude oil annually. This reduces sludge disposal and generates a source of fuel.

The pilot project is ongoing, and expected to be completed by 2023. The results of the pilot project will be used to evaluate the feasibility to expand the scope and scale of hydrothermal wastewater processing.



Water Resource Foundation, “HYPOWERS: Hydrothermal Processing of Wastewater Solids,” 2019.

Bolzano Waste-to-Energy Plant

LOCATION
Bolzano, Italy

COSTS
$125 million

CAPACITY
130,000 tons/year

OUTPUT
95 GWh/year electricity, 240 GWh/year heat

POPULATION
521,000

TECHNOLOGIES
Incineration, combined heat and power

CONSTRAINTS
Emissions standards, aesthetic considerations

The Bolzano waste-to-energy plant generates electricity and heat for the city of Bolzano using solid waste received from 116 municipalities in the surrounding province.[67] The plant can process 130,000 tons per year using incineration and combined heat and power equipment.[68] The electricity produced is used to operate the plant and sold to the national grid while the heat generated is distributed to buildings via the city's district heating system.[69] In 2016, 3,500 homes and 100 shops were heated through the district system, which is proposed to be expanded.[70] The further use of heat from the waste-to-energy plant is proposed to replace current heating units, leading to a projected 20% reduction in regional air pollution.[71] The reusable metals are separated from solid materials left over after incineration and the remaining ash and slag are sent to recovery plants.[72] The gaseous emissions from the plant are filtered to meet provincial regulatory standards and are continuously monitored, both by the plant operators and by the provincial supervisors via remote access to the emissions database.[73]

Beyond waste treatment and energy production, the Bolzano plant plays an important role in education. The plant is located at the southern entrance to the city, so everyone coming from the highway sees the building as they arrive.[74] The architecture firm CL&AA designed the plant to emulate the surrounding mountains and provide a less visually jarring disruption to the landscape than a typical industrial plant would.[75] Green aluminum is used as a noise barrier for the building housing the turbine and transformers.[76] The use of color throughout correlates to the interior zones of the plant.[77] The Bolzano plant is designed to be open for tours and education, especially for students and professionals, with the aim of teaching the public more about waste management.[78]

Alessandra Chemollo, "Bolzano Waste to Energy Plant," 2014.

Amager Bakke Plant

LOCATION
Copenhagen, Denmark

COSTS
$600 million

CAPACITY
560,000 tons/year

OUTPUT
244 GWh electricity, 1.363 GWh heat

POPULATION
645,000

TECHNOLOGIES
Incineration, combined heat and power

CONSTRAINTS
Amount of local waste, reliance on imports, carbon neutrality compliance

The Amager Bakke Plant, also known as Copenhill, is a well-known example of creatively using a waste management site for education and entertainment while achieving high standards of environmental performance. This waste-to-energy facility began operating in 2017 and treats residential and commercial waste from five nearby municipalities, which jointly own the plant.[79] The solid waste, which is already separated from recyclables and organics, is brought to the facility by up to 300 trucks per day.[80] The plant is permitted to receive 560,000 tons of waste per year.[81] Furnaces incinerate the waste, which is used to heat up water, producing steam. The steam is used to generate electricity for the local grid, generating 244 gigawatt hours (GWh) in 2020, enough electricity for 80,000 homes.[82] The remaining steam is sent to heat homes through the regional district heating network and in 2020 provided 90,000 apartments with the equivalent of 1.363 GWh of heat.[83] The solid waste left after incineration is separated into reusable metals and the remaining bottom ash is used for road construction materials.[84] The gas emissions from incineration are treated with an advanced set of filters to remove most particulate matter and other pollutants.[85]

In addition to the high performing equipment in the waste-to-energy facility, the plant was designed to be a recreational attraction, acting as a destination rather than a detriment to nearby residents. The equipment is arranged by height to create a sloped roof for a ski slope the length of an Olympic half-pipe, with additional space for a freestyle park, and a slalom course, and practice slopes.[86] The slopes are lined with biodiverse plantings to provide the temperature and pollutant reduction benefits typical of green roofs.[87] The plant includes further opportunities for recreation and environmental education with a fitness center, an education center, and the world's tallest constructed climbing wall.[88]

Hufton + Crow, "Amager Bakke Plant," 2020.

The size of Amager Bakke has been criticized as the furnaces require more fuel than the local waste streams can provide.[89] To achieve the energy production required for the electricity and heat demand of the area, the plant has had to import waste from abroad.[90] Beyond the sizing of the equipment, the utilization of incineration has come under question as well. Using waste to provide energy and heat is less carbon intensive when compared to fossil fuels.[91] Denmark's transition to green energy sources means this plant providing energy increases the city's carbon emissions, which works against Copenhagen's carbon neutrality goals.[92] Amager Bakke is currently installing carbon capture technologies, which will result in annually capturing 500,000 tons of carbon dioxide.[93] The inclusion of carbon capture with waste incineration better align the plant with Copenhagen's ambitious plans.

Hufton + Crow, "Skiers on Copenhill," 2020.

Shenzhen Energy Renovation Plant

LOCATION
Yantian District, Shenzhen, China

SIZE
3.2 acre plant
10.9 acre site

TECHNOLOGIES
Perforated aluminum plates

CONSTRAINTS
Maintain functioning plant during construction

The Shenzhen Energy Renovation Project is a designed façade to cover the existing waste-to-energy plant in the Yantian District. The project, composed of a roof and chimney covering, serves as a model for other waste plants. Inspired by the movement of water down a mountain, Peijun Ye and Tongtong Hui of Hayer Design designed a landmark that modernizes the appearance of the plant, all while evoking the elegance of flowing water and connecting the building to the surrounding landscape.[94] As part of the circulation plan, a series of terraces draws visitors into the renovated plant, which includes an exhibition space for visitors, covered in a living green wall. The public engagement component of the plant was an important consideration to showcase China's innovation in the waste-to-energy space with a broader audience, and connect the plant to public life in Shenzhen.

The structure is made of white perforated aluminum plates, which are corrosion-resistant and have a long lifespan.[95] Additionally, the façade shades workers from the elements. Visually, the material is light, and the structure welcomes visitors to the plant, enabling comfortable walking tours and the reimagining the look and feel of waste treatment for the area.[96] The renovation was complete in 2017 and the plant continued operations during construction.[97]

Xiaodong Wang, Shan He Cheng, "Shenzhen Energy Renovation Plant," 2017.

Roskilde Incinerator Waste to Energy Plant

LOCATION
Roskilde, Denmark

CAPACITY
350,000 tons/year

OUTPUT
Electricity for 60,000 households/year

TECHNOLOGIES
Incineration, aluminum plates

Waste-to-energy plants provide 20% of Denmark's heat. The Roskilde waste-to-energy plant receives waste from nine nearby municipalities and from abroad.[98] The facility can process up to 350,000 tons of waste per year, generating enough electricity for 60,000 households annually.[99] This plant is unique for its façade. Outside the climatic barrier skin is a layer of umber-colored aluminum plates perforated with irregularly placed laser-cut holes.[100] The laser cut holes are illuminated with backlighting, which are programmed in an hourly nighttime display to evoke sparks growing into flames and then burning out into embers.[101]

The shape and color of the plant, including the spire, are meant to be in conversation with the nearby Roskilde Cathedral, as well as the city's industrial surroundings.[102] The plant is on the site of two former waste plants with lower capacities.

Tim Van de Velde, "Roskilde Incinerator at dusk," 2014.

Wonthaggi Desalination Plant

LOCATION
Wonthaggi, Victoria, Australia

COSTS
$3.5 billion

OUTPUT
160 billion liters/year

TECHNOLOGIES
Reverse osmosis, constructed dunes, green roofs, habitat restoration

CONSTRAINTS
Pumping height, coastal view

The desalination plant in Wonthaggi, Victoria is an example of an industrial facility working with the surrounding landscape. The plant treats seawater with reverse osmosis to produce drinking water and must be close to sea level to reduce the height seawater has to be pumped.[103] [104] One benefit to designing the plant to be as low as possible is that the architects were able to camouflage the industrial site using green roofs and constructed dunes.[105] The community had not wanted the appearance of the coastline to be affected, and this creative design alleviated their concerns.[106] Additional benefits of the green roof include acoustic insulation, heat reduction, and corrosion prevention.[107] The constructed dunes not only shield the plant from view, but actually restore the landscape that existed before farming practices led to widespread coastal erosion.[108] The dune reconstruction is part of a larger strategy of ecological restoration on the site, where 225 hectares have been rehabilitated with over 3.5 million new plants, 150,000 new trees, and restored wetland, coastal, and swampy woodland habitats.[109]

ARM Architecture, “View of desalination plant from the water,” 2020.

Funding Opportunities

Cape Ann should continue to seek out federal and state grant programs to explore waste to energy programs for the region.

Grant Programs

United States Department of Energy Technical Assistance Program
Experts at the federal Department of Energy will aid Gloucester, Manchester-by-the-Sea, Rockport, and Essex in further evaluation of the feasibility of a regional waste-to-energy facility.[110]

Gap III Energy Grant Program
The Massachusetts Department of Energy Resources and the Massachusetts Clean Energy Center jointly run the Clean Energy Results Program, which provides funding to energy efficiency, clean energy production, and energy storage projects through this grant program. Municipal wastewater utilities are eligible applicants and the 2022 grant cycle will fund up to $200,000 for eligible projects.[111]

Sustainable Materials Recovery Program Municipal Grant
The Massachusetts Department of Environmental Protection offers this grant to fund waste diversion programs, including composting and materials reuse. Eligibility criteria include a Buy Recycled Policy for purchasing, data reporting, and other compliance requirements.[112]

Green Communities Grant Program
Eligible municipalities in good standing with the Massachusetts Department of Energy Resources Green Communities Division are eligible to apply for an annual competitive grant to fund energy efficiency, renewable energy, and fossil fuel reduction measures.[113]

Municipal Energy Technical Assistance Grants
The Green Communities Division also offers a technical assistance grant program to third parties working with municipalities on the development of alternative energy initiatives.[114]

Building Resilient Infrastructure and Communities
The United States Federal Emergency Management Agency awards funds for capability- and capacity-building activities, mitigation projects, and management costs for large infrastructure projects that reduce the risk of natural hazards for a community. A municipality may apply as a subapplicant and must have an approved Hazard Mitigation Plan in place to be eligible.[115]

Other Funding

State Revolving Fund Clean Water Program
This state-run low interest loan program provides funding for projects that can demonstrate water quality benefits, such as wastewater treatment plant construction and upgrades. The program typically loans $400 to $450 million per year at a 2% interest rate, funding between 50 and 70 projects each year.[116]

Massachusetts Recycling Loan Fund
This low-interest loan program is funded by the Massachusetts Department of Environmental Protection to support businesses in materials recycling activities, including composting and anaerobic digestion. Though municipal wastewater treatment may not be eligible for this program, this could be an opportunity to fund innovative materials reuse.[117]

Proposed Recovery Operations on Cape Ann

Many technological innovations, including waste-to-biogas plants and hydrogen plants, will become commercially deployable by 2035. These plants will face increasing air and greenhouse gas regulations, coupled with increasing restrictions on solid waste disposal throughout Massachusetts, and the greater New England region.

These advancements will not solve the primary challenges for waste management on Cape Ann: first, collecting waste across the lightly populated and underdeveloped areas of the region is not cost-effective; and second, the municipalities do not individually produce enough waste to negotiate disposal contracts, and there is no cooperative structure to aggregate larger volumes.

Cape Ann should immediately operationalize its robust civic infrastructure to establish community compost drop-off programs and swap shops to reduce the amount of waste disposed on Cape Ann. The region should also explore public-private partnerships with golf courses for debris management after disasters.

A regional cooperative can accumulate regional waste to sell to contractors while municipalities apply for grants for a floodproof regional waste-to-energy plant to replace the aging Gloucester and Manchester-by-the-Sea wastewater treatment plants.

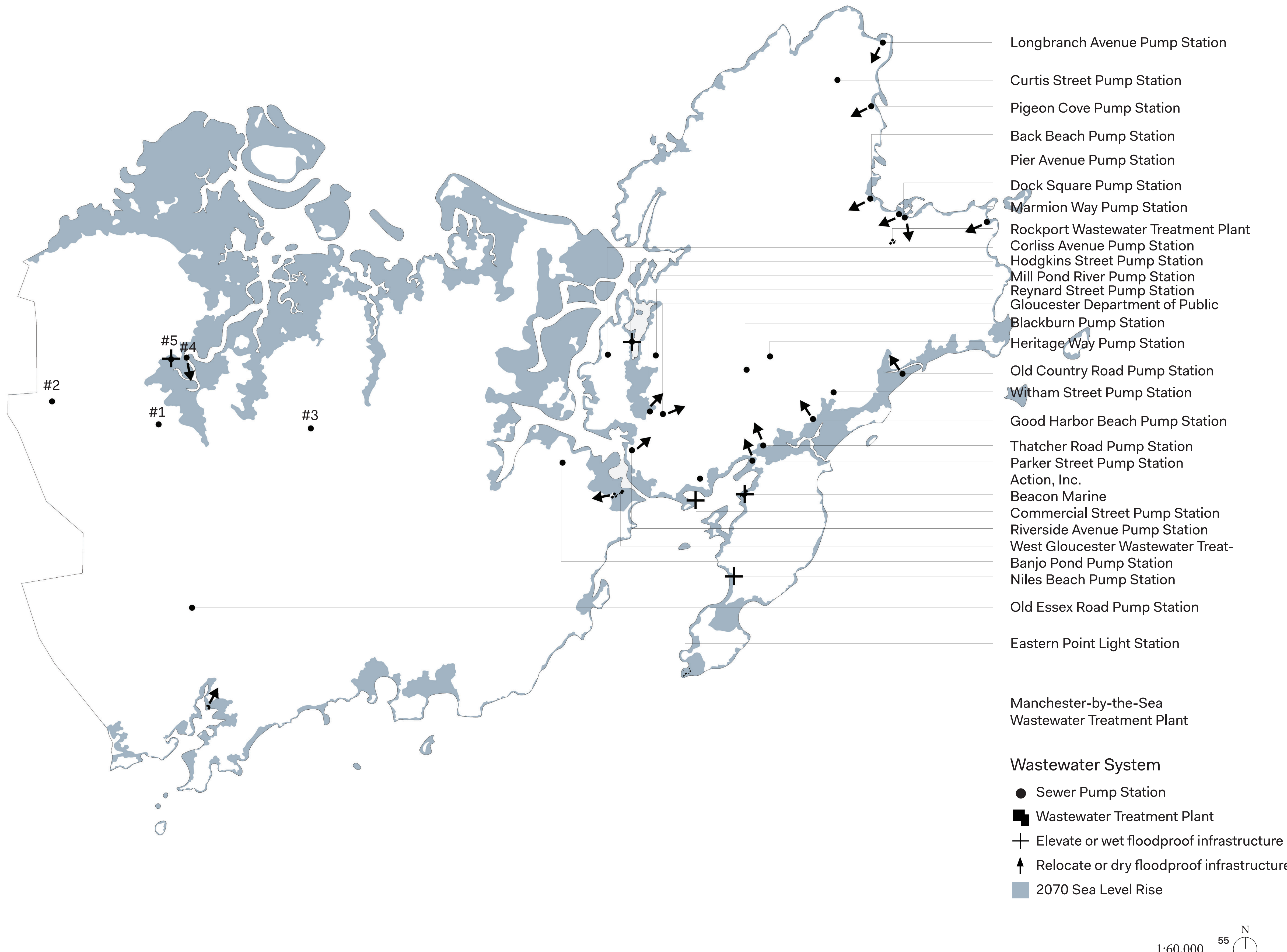
Existing Wastewater Treatment on Cape Ann

The wastewater treatment system on Cape Ann is extremely vulnerable to sea level rise and storm surge. Additionally, Gloucester is home to one of the last few obsolete primary wastewater treatments in the United States.

Both the Gloucester and Manchester Wastewater treatment plants will require updated plants by 2035.

The effects of flooding at the West Gloucester Treatment Plant or Manchester-by-the-Sea Plant would be catastrophic: effluent pouring out of the systems would flow directly into the Harbor, damaging sensitive habitats and decimating shellfishing beds.

This presents an opportunity to envision and implement a regional wastewater treatment system on Cape Ann that includes emerging waste-to-energy technology.



Existing Waste Disposal on Cape Ann

There are four closed landfills across Cape Ann. There are active transfer stations in each community, as well as the Black Earth Compost site in Manchester-by-the-Sea, a private company that operates on public land.

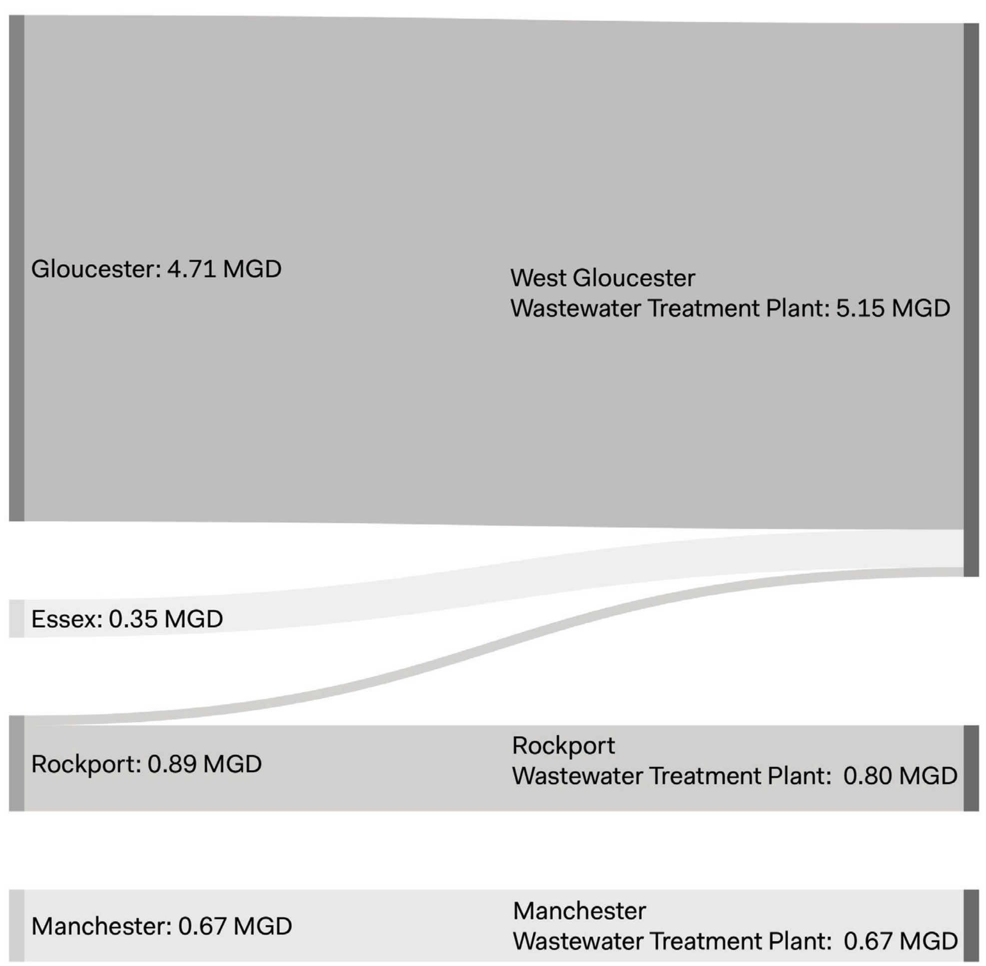
Rockport's transfer station includes a Swap Shop where residents bring gently used second hand items for residents to take home.

Existing Wastewater Treatment and Waste Disposal on Cape Ann

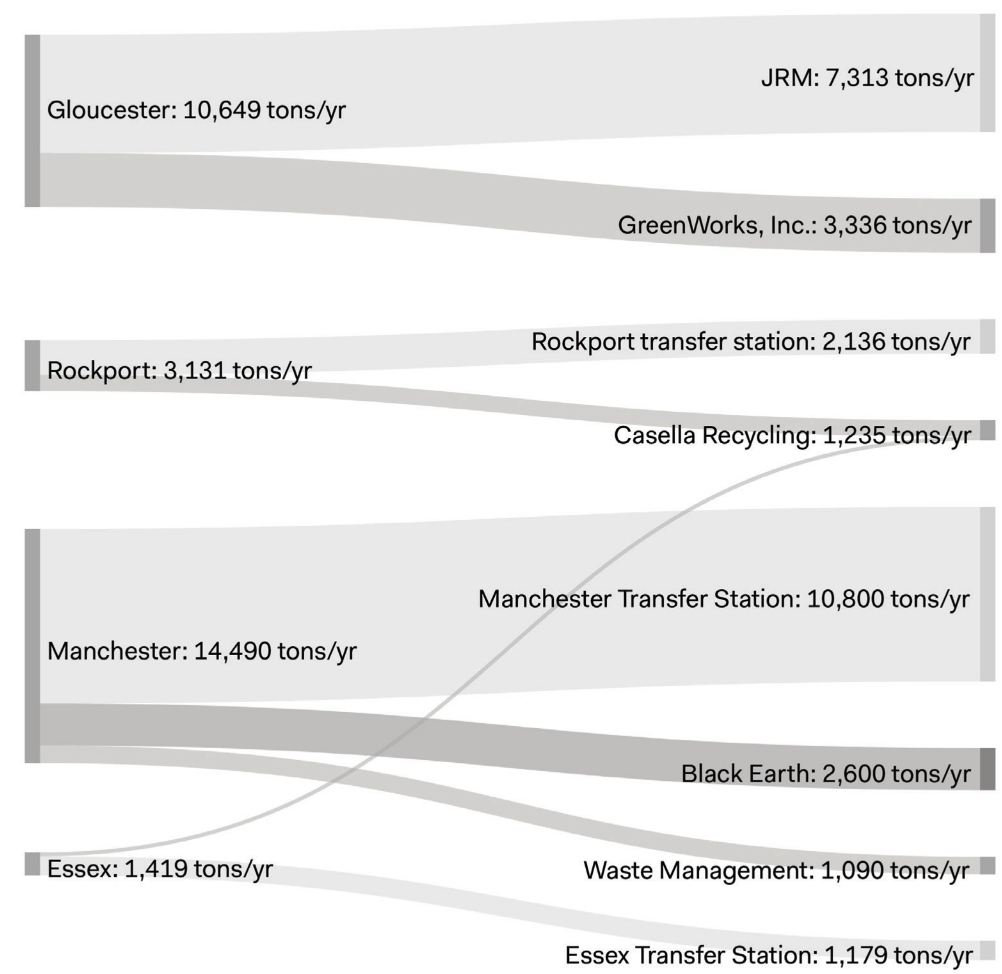
While the four communities currently share wastewater treatment capacity, there is no overarching regional wastewater management system.

Each municipality currently contracts with private companies for waste disposal. Gloucester, Rockport and Manchester-by-the-Sea use Pay-As-You-Throw programs, which reduce trash by 40%, as consumers elect to recycle materials to avoid paying a flat fee for garbage disposal.

Existing Wastewater Treatment (Million Gallons per Day)



Existing Waste Disposal (Tons per year)



Proposed Waste Infrastructure Programs

There is no single solution to Cape Ann's waste management issues. The existing transfer stations in each municipality are important facilities to aggregate materials into volumes that waste contractors can dispose of economically. Gloucester, Manchester-by-the-Sea and Essex should immediately work to build swap shops to reduce waste and foster a circular economy on Cape Ann.

Waste collection, especially in areas with dispersed single-family homes, is not cost-effective for taxpayers. Community compost bins in visible, public sites stewarded by garden clubs can reduce waste and provide topsoil. These sites must be central and convenient for residents to make trips, and can be sited near schools and community centers.

By 2035, a regional organics management facility located out of the floodplain can streamline the disposal of wastewater and solid waste and establish Cape Ann as a leading climate innovator in the developing waste-to-energy sector. This facility should include space for emerging technologies, including a hydrothermal processor to process the waste materials in these landfills, creating opportunities to remediate land to use for public open space.

Organics Management Facility and Education Center

Combined wastewater and anaerobic digestion plant with capacity for a hydrothermal processor on public site.

Waste Stream Material

Wastewater
Yard waste
Spent grain
Seaweed
Fish processing waste
Storm debris (trees)
Agricultural manure
Textiles

Size

8.5 acres

Considerations

Equipment
Road access
Storage
Parking
Elevation
Developable land
Flood zone

Potential Locations

Magnolia Woods
Old Salem Road
Stage Fort Park

Transfer Stations with Swap Shop Spaces

Local drop-off sites to aggregate trash, recycling, and compost materials with swap shops to reuse materials.

Waste Stream Material

Plastic films
Boat shrink-wrap
Agricultural mulch film
Hard-to-process plastics
Furniture
Lightly used second-hand materials

Size

0.4 acres/facility

Considerations

Staging area to aggregate materials
Existing local markets
Road access
Central location

Potential Locations

Existing transfer stations

Community Compost Sites

Local drop-off sites to compost food waste and collect soil in collaboration with local garden clubs.

Waste Stream Material

Food waste

Size

0.1 acres/site

Considerations

Road access
Central location

Potential Locations

Burnham's Field, Gloucester
Lanesville Community Garden, Gloucester
Stage Fort Park, Gloucester
O'Maley Middle School, Gloucester
Rockport Transfer Station, Rockport
Rockport High School, Rockport
Mill Brook Park, Rockport
Black Earth Compost, Manchester
Manchester-Essex High School, Manchester
Essex Transfer Station, Essex

Disaster Debris Management Sites

Staging area to collect and stockpile tree and brush debris after major storms to transfer to Organics Management Facility.

Waste Stream Material

Storm debris (trees)

Size

8 acres+

Considerations

Staging area
Road access
Stockpiling capacity

Potential Locations

Essex County Club
Cape Ann Golf Course

Proposed Cape Ann Waste Infrastructure

A network of waste management infrastructure across Cape Ann provides near- and long-term solutions. In the near term, community compost sites accept food waste, especially in Gloucester, Rockport, and Essex, which are not served by Black Earth Compost.

Swap shops reduce the amount of waste sent to contractors. In the long term, an Organics Management Facility produces energy from wastewater and organic materials that enter the Cape Ann electrical grid.

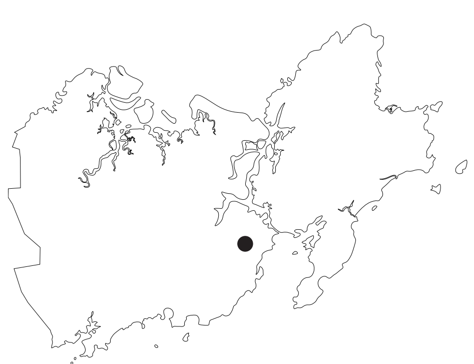
The facility must be located out of the floodplain, and should be sited in a public and highly visible location, with an education coordinator position included in the scope of work for the facility.

Proposed Organics Management Facility: Old Salem Road, Gloucester

In the event of an emergency, an Organics Management Facility in west Gloucester will be easier to reach than a facility located in east Gloucester or Rockport.

The parcel around Old Salem Road in West Gloucester includes forested open space that could be developed into a waste processing plant out of view of the community.

An additional parcel by the Kondelin Road Industrial Park could be investigated for a management facility.



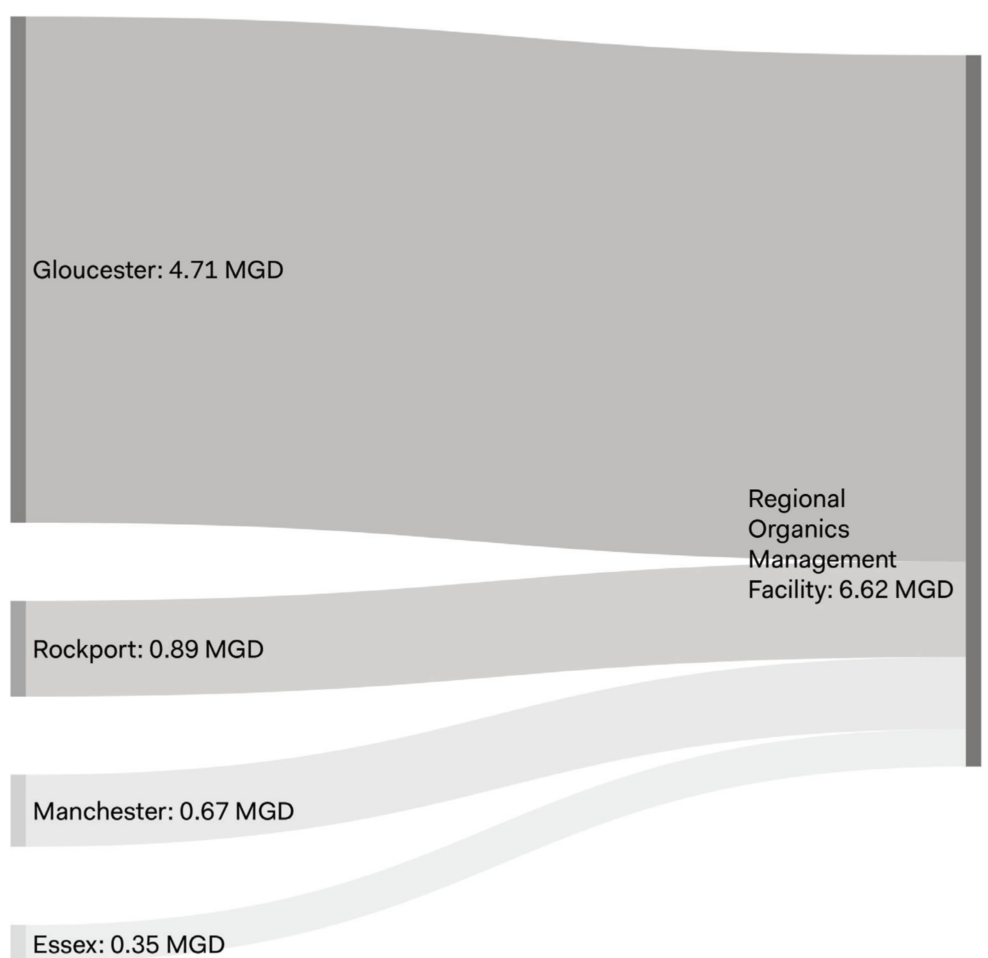
Proposed Waste Disposal

Adding a municipal compost program similar to Manchester-by-the-Sea can reduce solid waste production by 35 to 50%. This number can be further reduced by random waste audits that ensure that the compost is of high quality. A proposed waste-to-energy plant would treat material that cannot be recycled or composted.

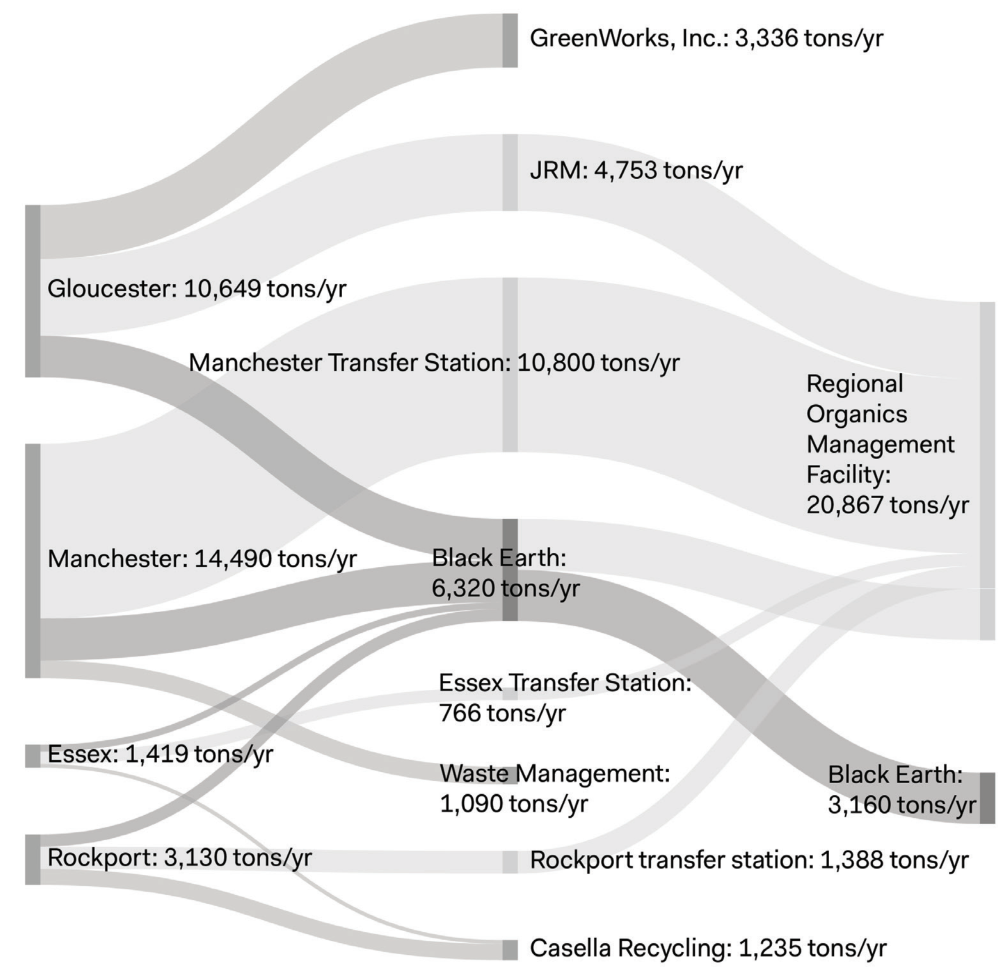
Adding resource recovery to the end of the waste stream would not impact existing recycling practices. Current methods of waste collection could be used and then material moved from the existing transfer stations to the proposed energy plant.

The proposed waste treatment plant could receive organic material collected by Black Earth for co-digestion and biogas production, though organic material would still be composted.

Proposed Wastewater Treatment (Million Gallons per Day)

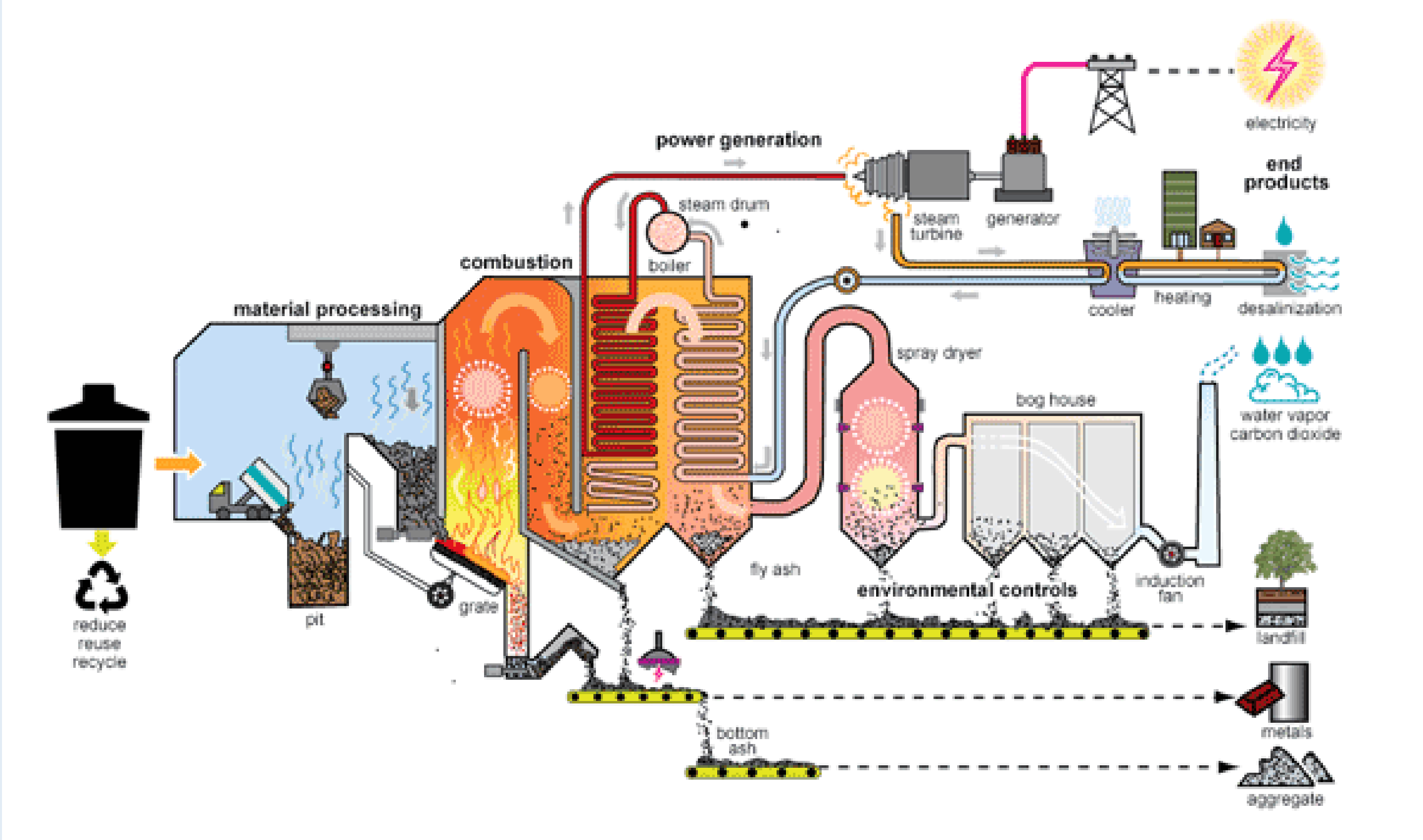


Proposed Waste Disposal (Tons per year)



Waste Recovery: Emerging Technologies

Treating waste is an essential function of municipalities. Recent advancements in technologies to treat solid waste and wastewater can produce energy to feed into the electric grid and create new opportunities to engage the larger community in the transition to a just, climate-conscious economy.



Deltaway, “Waste-to-Energy: How It Works,” *Clean Energy Wire*, May 2021.

Types of Municipal Waste

There are two main forms of waste. The first, "wastewater," generally comprises anything that runs down the drain and enters septic tanks or sanitary sewers. The second is "solid waste," which is typically trash, recycling, and compostable material that is collected curbside or dropped off at a central point. Solid waste management strategies vary according to the resources and demands of each municipality. Wastewater treatment is highly energy intensive and treatment plants are designed to have a lifespan of fifty years.[118] The specifics of wastewater treatment also vary, but the general approach is standard: wastewater enters a plant and is transformed, through a variety of processes, into treated water, gas, and stable and nutrient-rich solids. Each of these outputs may be used or disposed of differently depending on the capacity of the plant and the regional demand for each product. Recently, the energy potential of waste has been considered a valuable potential output of treatment processes.

The decisions made regarding wastewater and solid waste treatment strategies have long-term implications for energy demand and material output due to the longevity of this high demand. Current research suggests regional wastewater treatment and the use of co-digestion for biogas production as an effective means of both wastewater treatment and energy production.

Loxahatchee River Environmental Control District, "Secondary clarifiers," 2018.

Wastewater Treatment and Flood Risk

Wastewater treatment plants (WWTPs) are often sited in low-lying areas near bodies of water.[119] Siting WWTPs at low elevations reduces the number of pumping stations needed to bring waste to the plant.[120] Plants must discharge effluent produced from the wastewater treatment process into a body of water, so siting WWTPs near rivers or oceans reduces the energy and materials required to transport effluent.[121]

However, placing WWTPs near bodies of water often sets them in flood-prone areas; as a result, coastal WWTPs are often vulnerable to sea level rise. A one-foot increase in sea level would put sixty treatment plants at risk in the United States, affecting no less than four million people.[122] Sea level rise will also lead to surface flooding and may prevent effluent from leaving outfalls if the water level is higher than the pipe.[123] Rising groundwater, another consequence of sea level rise, could lead to permanent inundation and reduced capacity for storage or conveyance if pipes are not fully sealed.[124] Recent research has documented the negative impact of groundwater inundation on coastal wastewater infrastructure due to rising sea levels.[125]

Coastal WWTPs are also vulnerable to flooding from severe weather events and storm surges. Flooding poses multiple challenges to WWTPs. It can damage facility equipment and cause power outages, which in turn stops service and requires expensive repairs.[126] Saltwater flooding in particular can corrode equipment.[127] Moreover, protecting treatment plants from shoreline flooding can be intensive and expensive. Protective infrastructure includes pumps, levees, and sea walls, though groundwater rise would require additional pumps to remove water from behind the levees or sea walls.[128] Repairs necessitated by flood damage to mechanical, structural, and electrical equipment are also expensive.

Failure to prevent flooding has serious consequences for a WWTP and its surrounding area. When service is stopped or when the equipment is overwhelmed with too much water, untreated effluent is released.[129] The WWTP may also discharge untreated effluent when it is overwhelmed by rainwater that enters the system via the storm sewer in a combined system, an event called a combined sewer overflow (CSO). Combined sewer systems have been shown to lead to greater amounts of pathogens at a WWTP than separate systems.[130] CSOs have significant negative impacts on ecological systems, human health, and regional economies. Such impacts include the increased presence of bacteria, viruses, toxic chemicals, and microbiological pathogens; ecological impacts include algal growth, and changes in water temperature, turbidity, and pH; and economic impacts include lost revenue

Karl Spencer, “Wastewater treatment plant flooding in Hurricane Harvey,” 2018.

from closed beaches, the disruption of commerce, property value decline, and the cost of cleanup.[131]

Relocation and Regionalization

A long-term solution to reducing flood risk at a WWTP is relocating the plant. This is a challenge in areas with little land availability and high property values.[132] Other than property acquisition, costs associated with relocating a WWTP include plant construction and restructuring the upstream sanitary sewer infrastructure.[133] Since moving the WWTP out of the area of flood risk will likely mean moving it upland, additional pump stations may need to be built. When relocating a plant, municipalities should consider the lifespan of the existing plant, any scheduled repair of existing infrastructure, and the timeline of coastal flood risk to decide when to phase out improvements to the existing plant and when to build a new one.[134]

Relocating a plant is an opportunity to provide regional treatment. One benefit of a centralized WWTP is efficiency, as flood protection only needs to be implemented at one plant.[135] Another benefit of regional treatment is that is may allow for alternative treatment processes that are more effective at a larger scale. However, this approach removes potential redundancy in the system, which means if the plant is inoperable, there is no other site to send the waste.[136] Networked wastewater systems in which waste can be rerouted between plants are not common, but this could be an opportunity to consider the benefits of a dispersed and networked regional system.

Energy Production

Wastewater treatment is an energy-intensive process. Energy demand is projected to increase as effluent treatment standards rise due to population growth and stricter environmental regulations.[137] Climate change may affect wastewater treatment by reducing the effectiveness of biological processes used in the plant.[138] This could further increase the energy demand of WWTPs if effectiveness reduces as standards and quantity are rising. These factors, along with the need for carbon neutrality, mean that WWTPs should be made as efficient as possible and implement practices to reclaim all available materials and energy from the treatment process. Potential materials for reuse include water and nutrients. The energy potential of wastewater is in the organic and thermal content of sewage.[139]

New York Department of Environmental Protection, “Biodigesters,” 2014.

Biogas

Certain wastewater treatment processes are more conducive to resource capture and reuse than other widespread methods. One of the most important types of energy capture involves biogas, which is a byproduct created during the treatment of "sludge," the solid component of waste. In this process, sludge is treated with thermal hydrolysis to maximize the potential amount of methane.[140] It then undergoes anaerobic digestion to break down into a more easily treatable solid product with a byproduct of biogas.[141] Sludge can be treated further for use as digestate, which can be applied to soil as fertilizer.[142] Biogas is then captured and used for energy production—either onsite or elsewhere—if converted to natural gas.

It has been estimated that biogas can produce up to half of the energy to meet the overall electricity demand of wastewater treatment and that, generally speaking, WWTPs have the capacity to produce 60% of their own energy and 100% of the heat needed for operation.[143] As of 2021, however, less than 10% of WWTPs in the United States use biogas and just a few (mostly the largest plants) produce more energy than they consume.[144] However, as technological advances continue and domestic energy policy encourages alternative fuel sources, biogas may become more affordable and cost-effective.[145]

On-site energy production increases WWTP resilience by reducing its dependence on external fuel sources. If it uses captured biogas as an energy source, a plant would not need to stop its operations during power outages or other fuel shortage events.[146] This energy independence also reduces overall reliance on extractive fuels, which has immediate financial benefits for the WWTP and contributes to broader positive environmental, health, and economic impacts. Burning biogas-produced methane, while not carbon-zero, is preferable to releasing it into the atmosphere because combustion turns methane into carbon dioxide, a significantly less harmful greenhouse gas.[147] As this technology continues to develop and become more broadly implemented in the United States, the efficiency of its domestic application will improve and further energy production methods should be realized.

Biogas Tønder, "Large-scale biogas equipment," 2020.

A potentially negative consequence of expanding the use of biogas is the potential expansion of natural gas infrastructure when used beyond the confines of the WWTP.[148] Some environmental groups support the conversion of waste to electricity instead, to negate this use of methane and prevent further expansion of natural gas infrastructure.[149] Tom Cyrs of the World Resources Institute poses the following questions to consider the emissions associated with using biogas: "Are they capturing and avoiding more methane emissions than would otherwise occur? Are they resulting in a more productive use of these wastes than would otherwise occur? And are they piggybacking on fossil fuel infrastructure, rather than resulting in the buildout of a large number of new natural gas pipelines?"[150] The role of biogas in decarbonization is dependent on the energy transition strategy of the surrounding region. These nuances will only become more important as biogas capture technology improves and the practice is more widely adopted.

Co-Digestion

Food waste and manure may be added to wastewater treatment processes to increase biogas output in a method called co-digestion. This created improved conditions for digestions through waste components (such as acidity and dilution) and the addition of substrates.[151] Anaerobic digestion equipment is often designed to treat more effluent than the plant receives, so another benefit of expanding the feedstock to include food waste is that the equipment can be used at full capacity.[152]

There are significant environmental benefits to utilizing co-digestion for materials that would otherwise be sent to landfills, which are the third largest source of methane emissions in the United States.[153] Diverting this material for the production and use of biogas to power wastewater treatment, a necessary use of energy, can reduce the need for landfills and lower overall methane emissions. Additionally, the increased efficiency offered by onsite biogas production and co-digestion equipment can lead to cost savings. For example, Oakland, California saved $3 million on electricity bills each year by adding organic waste to its wastewater treatment process.[154]

Co-digestion and use of additional organic waste in a WWTP have several potential negative effects, particularly if not properly implemented. The cleaning of food waste before use at a WWTP can be challenging, which is a barrier to using co-digestion.[155] The environmental benefits demonstrated in the Life Cycle Assessment of a WWTP in Bath, New York found that the proper management of compost was the most important factor in minimizing greenhouse gas emissions.[156]

OCWA, "Aerial view of clarifiers," 2020.

Composting Technologies

Composting is the processing of organic waste into useful materials, typically compost for agricultural and residential use. A successful municipal composting program generally requires a nearby facility capable of processing the projected amount of organic waste collected.[157] Though a facility can be built specifically for a composting program, cities often expand their existing yard waste processing facilities or contract with an established private composting facility. In some cities, organic material is sent to the municipal wastewater treatment plant for co-digestion to produce additional biogas for the plant, as previously described. Residential and community-organized composting can be encouraged to divert solid waste from landfills, as well.

The collection of organic material for composting can be understood through its composition and its method of collection. Organic material can be collected through mixed waste stream collection in which all solid materials are collected at once and then the organics are sorted at the facility. This method has been demonstrated to send 60 to 70% of the collected solid waste to composting.[158] The other composition of material is source-separated organics, in which compostable materials are separated from other waste before they enter the facility. The sorting is done by the waste generators and has been shown to divert 40–50% of solid waste for composting.[159] Compost operations must diligently test for Per-and Polyfluoroalkyl Substances (PFAS), a group of chemicals used to manufacture stain-resistant, water-resistant, and non-stick products. PFAS can leach into groundwater from composted materials, and accumulate in the food chain, causing potential health problems.[160]

There are two typical strategies for organic waste collection. The first is a drop-off approach in which waste generators bring their organic waste to a site, such as a compost processing facility or transfer facility. The second is curbside organics collection. This method requires the participation of haulers: either a municipality-provided hauling service or a contracted company whose routes and collection methods can be modified to include organics.[161] Additionally, waste generators need to be encouraged to utilize the curbside collection service and educated on acceptable composting material to minimize the contamination of organic waste.[162]

Justin Sullivan, “San Francisco compost facility,” 2020.

Conversion Technologies

Biogas production and co-digestion are examples of "conversion technologies," that is, the creation of products, chemicals, and fuels from solid waste. In this they "represent the next evolutionary step of solid waste material recovery systems, diverting organic (carbon-containing) solid wastes from the traditional disposal activities of landfilling and Municipal Solid Waste combustion."[163] The materials used for conversion are separated solid wastes including manure, food waste, fats, oils greases, plastics, and tires.[164]

There are three broad categories of conversion technologies: biochemical, thermochemical, and physiochemical. Biochemical processes include anaerobic digestion and fermentation and encompass the strategies of biogas production, co-digestion, and composting.[165] Thermochemical processes include gasification, pyrolysis, and thermal depolymerization, which can create fuel, electricity, chemical products, and activated carbon.[166] Physiochemical processes include transesterification (biodiesel production) as well as physical and chemical synthesis to create fuel.[167] These technologies can occur at the same site. For example, Fiberight LLC, a facility near Bangor, Maine, includes—in addition to typical recycling processes—conversion of fiber to pulp, organics to natural gas (via on-site WWTP), and plastic film to fuel.[168]

Conversion technologies are often compared to waste-to-energy (WTE) plants (where waste is burned to produce electricity) and to landfills (where waste is buried). There are a variety of benefits to conversion technologies in both of these comparisons. Unlike WTE and landfills, conversion technologies allow materials to be recovered and turned into useful products.[169] Not only can conversion technologies create fuel and reduce the need for fossil fuel extraction, but they often create more energy than WTE and landfills while generating less air pollution and carbon dioxide.[170] Given their low cost of electricity, conversion technologies to create materials, rather than electricity, may be more economically viable than WTE plants.[171]

There are several downsides to conversion technologies that should be considered. The approach is not yet widespread in the United States, so there is risk in investing in a sector with limited experience.[172] Some materials that could be recycled or composted may be diverted to conversion technologies, which may prevent future investment in other, potentially higher-performing methods of recycling and composting by locking in the waste-to-materials stream.[173]

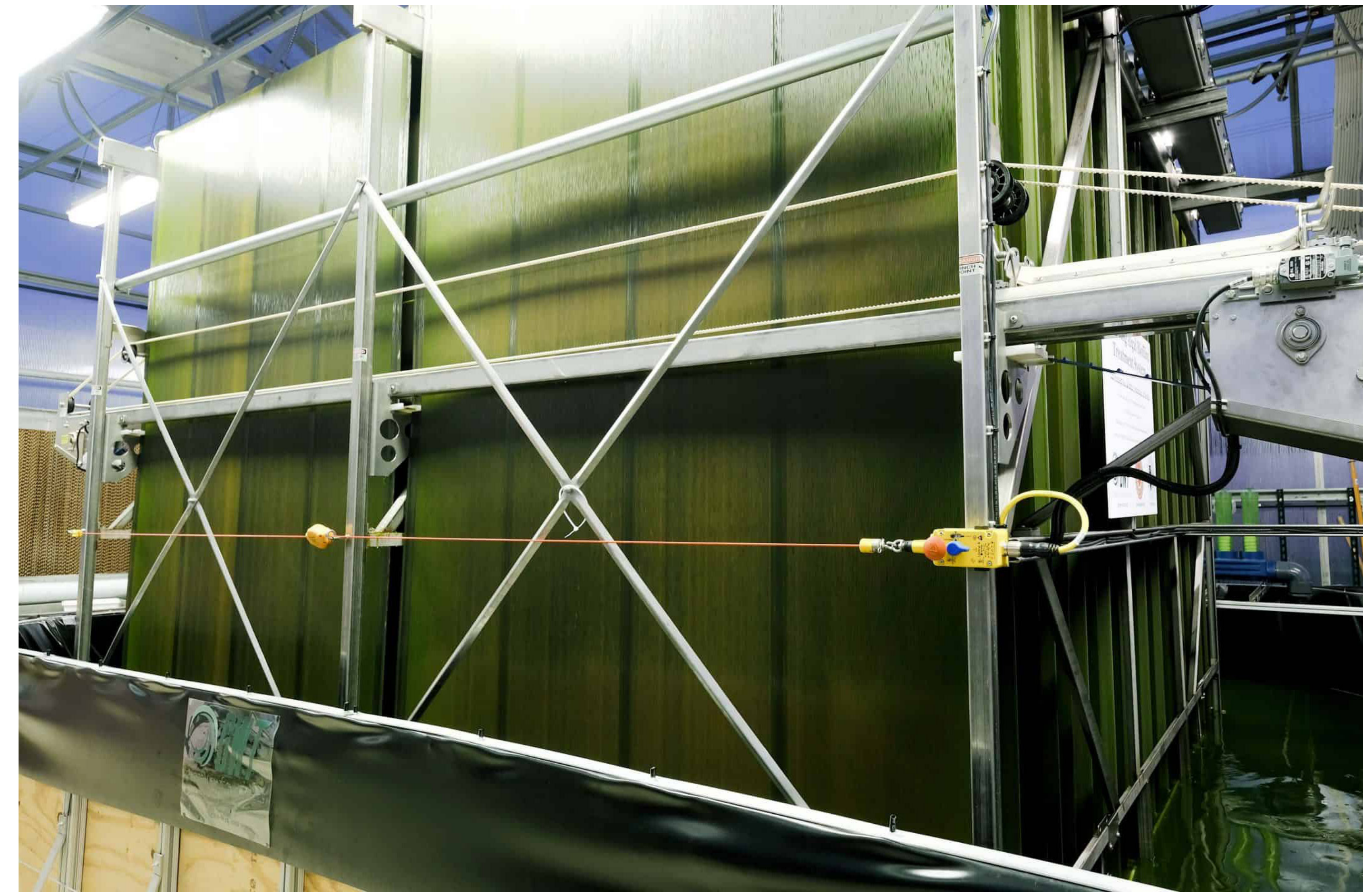
Waste conversion demonstration facility, *Plasco Energy Group*, 2014.

Developing Areas for Future Investigation

Wastewater treatment and waste conversion are industries with significant inertia. The high cost of installing new technologies and the high risk associated with potential failure means that, understandably, the industry's best practices are well-worn. However, innovation is occurring. Technologies for wastewater treatment and energy production that have not yet found widespread footing include microbial fuel cells, chemical fuel cells, and membrane processes.[174]

Vladimir Novotny has proposed that hydrogen-based systems could replace landfilling by the indirect gasification of organic solids followed by hydrogen fuel cells. His research suggests that the process could be fully decarbonized and produce energy, concentrated hydrogen, fertilizers, oxygen and ozone, as well as concentrated carbon dioxide.[175]

Heat pumps, another method of energy conversion, could be used to generate energy at WWTPs using the thermal potential energy of waste.[176] An ongoing area of research considers algae (along with other biomaterials) as both a method for and a useful byproduct of the wastewater treatment process.[177]



Wastewater treatment with algae. *Gross-Wen Technologies,* 2021.

Waste Recovery: Cape Ann Context

Each municipality in Cape Ann currently oversees its own wastewater treatment and solid waste management. Starting by aggregating their waste materials, including trash, recyclables, and organic compost, the four communities on Cape Ann can collaborate to attain the most favorable rates with vendors. By 2035, the municipalities should combine their waste management practices into a regional treatment strategy.

David Ryan, “Landfill space in Massachusetts dwindles,” *The Boston Globe*, July 19, 2021.

Context: The Waste Crisis in the Commonwealth of Massachusetts

The Commonwealth of Massachusetts is facing a waste crisis, as neighboring states close their landfills to waste exported from the Commonwealth. Massachusetts produces 5.5 million tons of trash annually and sends roughly 2 million tons out of state. In the near future, Maine and New Hampshire will close their landfills to waste from Massachusetts. The Commonwealth also passed a ten-year solid waste reduction plan in 2022, which calls to cut the amount of solid waste going into landfills by 30% by 2030 and 90% by 2050. In order to meet this goal, recycling and reuse programs need to be expanded immediately.[178]

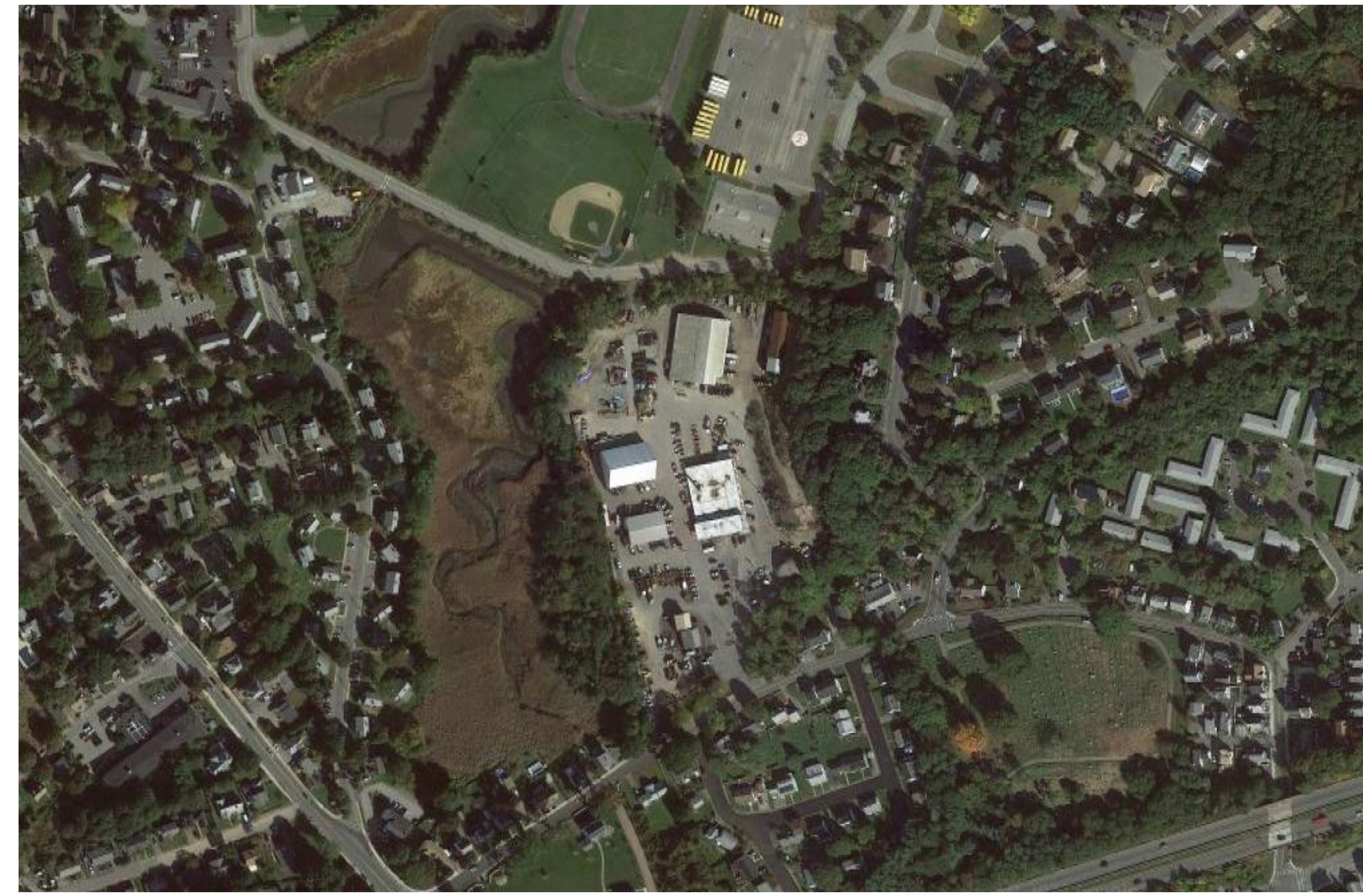
Essex County can assist the towns to contractually aggregate residential waste streams, including residential waste, commodity recovered recyclables, organic food waste, textiles, mattresses, and bulky materials.

Cape Ann

By aggregating larger material volumes, the towns can negotiate for collection and reycling at the most favorable rates with vendors. This collaboration can serve as a foundation and organizational effort for future regional efforts. The communities on Cape Ann generate over 11,608 tons of trash annually, or 500 pounds per capita.

On Cape Ann, wastewater is generally sent to a treatment plant or treated using a septic system. Gloucester, Manchester-by-the-Sea, and Rockport each operate their own wastewater treatment plants, while Essex contracts with Gloucester for use of its plant. Collectively, the region treats approximately 6.62 million gallons of wastewater per day.[179] [180] [181] Waste is collected at municipal transfer stations and hauled by contracted private companies.

By 2035 the age of Cape Ann's treatment plants, combined with the relatively small amount of waste generated by Manchester and Essex, may mean that the Cape's wastewater can be more efficiently treated in a regional system. In addition, Rockport's geographic separation from the rest of the region means that its wastewater infrastructures must also run through Gloucester, suggesting that a combined system may be more cost-effective.



Google Maps, "Gloucester Department of Public Works," June 21, 2022.

Gloucester

Wastewater

Sewage in Gloucester is treated by the West Gloucester Wastewater Treatment Plant (WGWTP). The facility was built in 1984 and is permitted to treat 5.15 million gallons per day (MGD).[182] It is located on Essex Avenue in West Gloucester and discharges to Massachusetts Bay, with overflows to Gloucester Harbor.[183] The WGWTP is at high risk of coastal flooding and adapting the plant for flood resilience is a top priority for citizens.[184] The WGWTP's vulnerability puts public health and safety at risk, as any failure threatens water contamination, groundwater leaching, and disease outbreaks alongside the significant negative economic impacts caused by disrupted service and the cost of repairs.[185]

The city has invested in several resilience plans and projects aimed at safeguarding the wastewater infrastructure system. The city applied for the Massachusetts Office of Coastal Zone Management Coastal Resilience Grant Program in 2019 to assess means of protecting the WGWTP from flooding, looking primarily at structures like berms in combination with operational changes to the plant.[186] The urgency of addressing flooding at the WGWTP is in recent memory for the city; in 2018, storm surge and coastal flooding overtopped the seawalls and flooded the access roads.[187] Though service was not disrupted, staff was unable to enter the WGWTP to assess the damage or modify on-site operations.[188]

In 2020, the City approved a $4.2 million loan to protect the plant with three different types of walls: masonry blocks, earthen berms, and sheet piles.[189] The walls surround the plant along Essex Avenue, and around the marshes on the northwest and southeastern edges of the campus. In 2022, Gloucester Mayor Verga announced his plan to conduct a feasibility study for a second wastewater treatment facility at the same location on Essex Avenue at an estimated cost of $100 million.[190]

The City has already begun rehabilitating its sewer pump stations and dry floodproofing them against storm events. The Riverside Avenue and Niles Beach sewer pump stations are currently being upgraded with above-grade electrical enclosures and watertight access hatches. These measures bolster the resilience of the City's wastewater treatment system.[191]

Kim Smith, "Raw sewage spill into the Great Salt Marsh," *Good Morning Gloucester*, May 29, 2018.

Beyond the WGWTP, the city is upgrading the existing sanitary sewer system. This involves separating the stormwater and wastewater sewers to prevent combined sewer overflows during flood events. As of 2022, there are four combined sewer outflows (CSOs) and the Wastewater Treatment Plant that discharge into Massachusetts Bay and Gloucester Harbor.[192] Additionally, the City has eliminated the CSOs in Great Harbor Swamp, which requires ongoing maintenance to prevent future flooding. The City also upgraded failing septic systems in the Cedarwood Road and Fenley Road neighborhoods, but these areas require additional public education and outreach to prevent future violations of septic regulations.[193]

Solid Waste
Gloucester services 13,500 residents with its municipal trash and recycling program that offers weekly curbside pickup through JRM Hauling and Recycling Services.[194] The City uses a pay-as-you-throw program in which residents purchase individual City-designated bags to dispose of waste. The City disposes of 7,312 tons of trash and recycles 3,335 tons of waste annually.[195]

There is no municipal composting program. Residents contract with independent contractors, including Black Earth Compost, which serves 580 residential homes with weekly curbside pickup, as well as twenty commercial contracts across the City. In addition, Gloucester maintains a compost facility on Dogtown Road that accepts brush, leaves, and yard waste.[196] The facility is only open once a month for residential drop-off. The city does not provide compost collection or food waste composting. The City estimated a curbside composting program would cost roughly $250,000 annually in 2017, which would not be offset by the savings to reduce solid waste, which were estimated between $50,000 and $75,000.[197] The Gloucester Landfill on Western Avenue was closed in 1952 and capped in 1998.

Neptune's Harvest, located in the Kondelin Road Industrial Park, also sells liquid fertilizers made from fishing industry products, including seaweed, fish, crab shell, lobster shell, and kelp meal fertilizers.[198]

Kim Smith, "Backyard Growers," Good Morning Gloucester, July 17, 2017.

Rockport

Wastewater

The town of Rockport operates an inland wastewater treatment plant on Pleasant Street, outside of any FEMA flood zones or areas of localized flooding.[199] The plant, which was built in 1976, treats 800,000 gallons per day using a fine bubble aeration system that discharges to Bearskin Neck.[200] The town has implemented ongoing maintenance and inflow and infiltration upgrades to the sewer system in coordination with pavement repairs and roadwork.[201]

Solid Waste

Rockport services 3,230 residents with its drop-off municipal trash and recycling program, located at a single transfer station, which also has a swap shop where residents can bring previously used items.[202] The Town uses a pay-as-you-throw program, where residents purchase individual City-designated bags to dispose of waste. The City disposes of 2,135 tons of trash and recycles 373 tons of waste annually.[203] The town does not offer curbside waste collection or municipal composting services, though 210 residents use Black Earth Composting for curbside pickup. The Rockport Landfill was closed in 1995 and capped in 2001.

Manchester-by-the-Sea

Wastewater

Approximately half of the town of Manchester-by-the-Sea is served by a sewer system, with the remainder treated by septic systems.[204] The town operates a wastewater treatment plant (WWTP) that was built in 1998 and permitted by the EPA for an average daily flow of 1.2 MGD. The plant provides first and secondary treatment. The WWTP is located on Chapel Lane and outfalls in Manchester Harbor, near Misery Island.[205] Under the Ocean Sanctuaries Act, the plant is only allowed to release 0.67 MGD, which results in inefficiencies and operational challenges due to the oversizing of equipment.[206] The WWTP is also not permitted to bypass treatment, even during heavy flows caused by storm events.[207] As of 2019, the town was completing an Inflow and Infiltration Project to minimize additional water entering the plant unnecessarily.[208]

The Manchester-by-the-Sea WWTP is vulnerable to a wide range of weather-related events and impacts, including winter storms, flooding, high winds, coastal erosion, extreme temperatures, drought, sea level rise, storm surge, tsunamis, and wildfires. Of these, flooding poses the greatest and most pressing threat.[209]

The Manchester Cricket, “Black Earth Compost handles curbside pickup,” November 15, 2019.

In 2015, Manchester-by-the-Sea evaluated the WWTP using the EPA's CREAT (Climate Resilience Evaluation and Awareness Tool), proposing adaptation measures such as relocating the site, building a sea wall, and reducing inflow, infiltration, and leakage.[210] Relocating the WWTP would require including surface water discharge or groundwater discharge permits, which may be difficult to procure, and adding a pump station and force main to the existing WWTP to move effluent to the new site.[211] Hardening equipment against flooding on the existing site may be more cost-effective, especially if implemented one structure at a time.[212]

Solid Waste

Manchester services 2,407 residents with its weekly curbside and drop-off municipal trash and recycling programs, which are contracted with JRM Hauling and Recycling.[213] The Town uses a pay-as-you-throw program, in which residents purchase individual City-designated bags to dispose of waste. The City disposes of 980 tons of trash and recycles 1090 tons of waste annually.[214] A waste disposal site in North Andover incinerates approximately 9,600 to 12,000 tons of waste from Manchester-by-the-Sea each year.[215][216]

The town contracts with Black Earth Compost, which processes 231 tons of collected food waste and dropped-off yard waste at their facility on School Street.[217] The curbside donation program also includes clothing, bedding, towels, and other textiles. 800 residents in Manchester currently use the program. The site is permitted to take in 100 tons of compost each week. A new facility on Pine Street will accept 30 tons each week and transfer 150 tons to other sites operated by Black Earth Compost. The compost is made available to Manchester residents.[218] This composting program began in April 2014 and is estimated to be able to save the town $340,000 every five years by decreasing the amount of trash to haul. Black Earth does not manage or process water treatment sludge or paper mill waste to reduce the risk of contamination with PFAS.[219]

The Manchester Landfill was closed in 1955 and capped in 2000. Black Earth Compost is currently building a regional facility on the site of former landfill, including an indoor facility developed as a private-public partnership between Black Earth Compost and the Town of Manchester-by-the-Sea. The Town of Manchester will pay $50,000 annually for twenty years for curbside compost pickup available to all residents, in return for a twenty-year lease on municipal property.[220]

Fredrik Bodin, "Rockport Swap Shop," Good Morning Gloucester, December 9, 2014.

Essex

Wastewater

Essex is serviced mainly by septic systems.[221] The town does not have a wastewater treatment plant, instead transferring wastewater to the Gloucester WWTP for treatment under an Administrative Consent Order. Essex has constructed its own sanitary sewer and pump stations to transfer the collected sewage.[222]

Solid Waste

Residents drop off waste at the Essex Transfer Station and Recycle Center on Landing Road.[223] Essex contracts with Covanta Energy for solid waste disposal and to operate the transfer station. In 2018, Covanta disposed of approximately 1,180 tons of waste from Essex residents.[224] Essex recycles 240 tons of material per year as of 2022.

In 2022, the Town is exploring transitioning to a Pay-as-You-Throw system with WasteZero, which is estimated to reduce waste reduction by 40%, as consumers shift to recycle waste to avoid paying for trash bags. This contract would allow Essex Department of Public Works laborers to shift their energy and attention toward other public works services.[225] The Essex Dump on Martin Street and Essex Landfill on Landing Road were closed in 1971 and 1985, respectively.

Google Maps, “Essex Department of Public Works,” June 21, 2022.

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