Resources for renewable natural gas production in Hawaii

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Executive Summary

Feedstock resources for renewable natural gas (RNG) production by biological (e.g. anaerobic digestion) and thermochemical (e.g. gasification) conversion methods in Hawaii have been reviewed. Estimates of resources for biological production (wastewater, landfills, foodwaste) have the potential to support 13.2 million therms per year (1,390 TJ y^{-1}, note that 1 therm = 100,000 Btu) of RNG production statewide (Table ES1). Similarly, estimates of the combustible portions of construction and demolition waste and municipal solid waste have the potential to generate 70.8 million therms per year (7,470 TJ y^{-1}) of RNG production statewide. Honolulu has the largest resource base for these urban waste streams. Underutilized agricultural land resources in the state could support substantial RNG production from dedicated energy crops (~1,000 to 2,000 therms per acre per year (260 – 520 GJ ha^{-1} y^{-1})), although agronomic suitability of specific candidate energy crops would need to be evaluated and confirmed.

The estimates of potential RNG feedstock resources and RNG product provided in this report do not take into consideration factors including economics, accessibility of a resource, availability of complementary factors of production, or the political, social, cultural, or regulatory environment. These factors would need to be considered in order to assess viability. Location of resources and access to infrastructure needed to implement successful RNG production, transmission, and distribution would necessarily depend on site specific details which are not included in this report.

Table ES1. Summary of RNG potential (million therms RNG/year) from resources in Hawaii.

Resource Type	Maui	Kauai	Hawaii	Honolulu	State Total
Livestock Manure	*	*	*	*	*
Wastewater Treatment Plants	–	0.02	0.06	1.8	1.9
Landfill Gas	2.2	1.0	0.6	2.5	6.2
Food Waste portion of MSW	1.8	0.5	2.3	0.5	5.1
Combustible portion of MSW	12.7	6.8	18.9	3.8†	42.3
CDW	-	-	-	28.5	28.5
Agricultural and Forestry Residues	‡	‡	‡	‡	‡
Energy Crops	§	§	§	§	§
Totals⸙	>17	>8	>22	>37	>84

* Insufficient number and size of animal feeding operations to justify methane production and recovery
† Estimated amount that is currently landfilled exclusive of HPOWER use
‡ Insufficient available agricultural residues and ongoing forestry harvesting residues
§ Underutilized agricultural land resources in the State could support substantial RNG production from dedicated energy crops (~1,000 to 2,000 therms per acre per year)
⸙ Totals would be larger with implementation of energy crop based RNG production

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Nomenclature

Acronyms

AD	anaerobic digestion
AFO	animal feeding operation
Btu	British thermal unit
C	carbon
ca	per person
CAFO	concentrated animal feeding operation
C&C	City & County
CDW	construction and demolition waste
CH_4	methane
CO_2	carbon dioxide
CO_2eq	carbon dioxide equivalent
CO	carbon monoxide
EIA	Energy Information Agency
EPA	Environmental Protection Agency
FP	future potential
GHG	greenhouse gas
HRS	Hawaii revised statutes
H_2S	hydrogen sulfide
LCC	land capability class
LFG	landfill gas
LMOP	Landfill Methane Outreach Program
LNG	liquefied natural gas
LP	low potential
MC	Marine Corp.
MSW	municipal solid waste
N_2	nitrogen
NPDES	national pollutant discharge elimination system
O_2	oxygen
RNG	renewable natural gas
SI	International System of Units (SI, abbreviated from the French Système international (d'unités))
SNG	synthetic natural gas
SRNG	synthetic renewable natural gas
TS	total solids
VS	volatile solids
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
WWTP	wastewater treatment plant

Units

atm	atmosphere
Btu	British thermal unit
°C	degrees Celsius
ca	per person
°F	degrees Fahrenheit
ft	foot
ft^3	cubic foot
g	gram
GJ	giga Joule
gpd	gallons per day
ha	hectare
kg	kilogram
km	kilometer
lb	pound
L	liter
mg	milligram
m^3	cubic meter
mmscfd	million standard cubic feet per day
MJ	mega Joule
Mg	mega gram (1 Mg = 1 metric tonne)
PJ	peta Joule
scf	standard cubic foot
scfd	standard cubic feet per day
therm	100,000 British thermal unit
TJ	tera Joule
y	year

Note that U.S. customary units and International System (SI) units are included throughout the report, anticipating different preferences by prospective readership.

Note that the following presentation of units are used interchangeably:

$$UnitA/UnitB = UnitA\ per\ UnitB = UnitA\ UnitB^{-1}$$

1. Introduction

In 2008, the Hawaii Clean Energy Initiative began a concerted effort to move Hawaii toward a renewable energy future (HRS, 2018). While early focus has been on electricity from solar and wind, driven by renewable portfolio standards and a commitment to forego new fossil generating assets, an interest in making use of biorenewable resources has been an ongoing theme across energy sectors. This interest is demonstrated by the state legislative and executive branches, county governments, regulated and unregulated energy providers, community stakeholders, and consumers.

Renewable natural gas (RNG) is composed primarily of methane derived from carbon of recent biogenic origin, unlike fossil natural gas (NG) that derives from ancient carbon commonly associated with fuels such as coal or petroleum. Either of these latter two resources can be used to produce synthetic natural gas (SNG) by thermochemical energy conversion methods. In general, RNG has lower life cycle greenhouse gas (GHG) emissions than NG. Depending on resource (feedstock) and production method, net GHG emissions for RNG can range from -50 to 7 kg CO_2eq / therm (-480 to 66 g CO_2eq/MJ) (CARB, 2021; Serra et al., 2019). Fossil natural gas has net GHG emissions of about 7.4 kg CO_2eq / therm (70.1 g CO_2eq/MJ) (CARB, 2021). The objective of this study is to explore production resources for RNG in Hawaii. The production of RNG makes use of biological or thermochemical conversion processes. Both are described in more detail below. Existing sources of biogenic methane in Hawaii that could be used to produce RNG are explored. Biomass resources that are used as the carbon feedstock for RNG production are also discussed and their occurrence in Hawaii reviewed.

RNG has the potential to directly displace incumbent fossil energy products (substitution) or to be part of a retrofit or new equipment package that would displace both the fossil fuel and end-use conversion technology. An example of the former is substitution of RNG for fossil gas use in process heat applications, whereas an example of the latter is a diesel engine replaced with an engine fueled by compressed RNG.

To provide context for the remainder of the report, Hawaii consumption of fossil energy products with potential for displacement by RNG were reviewed. Data from the U.S. Energy Information Agency (EIA, 2020) for 2018, the most recent year with complete reporting, are presented below. Three EIA categories of fossil energy products were identified;

(1) *natural gas excluding supplemental gas fuels* – includes 0.2 trillion Btu (2 million therms, 211 TJ) of imported liquefied natural gas (LNG),

(2) *natural gas including supplemental gas fuels* – includes the LNG from (1) above and synthetic natural gas (SNG) produced from petroleum naptha feedstock, and totals 3.2 trillion Btu (32 million therms, 3.4 PJ),

(3) *hydrocarbon gas liquids* – includes natural gas liquids and refinery olefins totaling 3.7 trillion Btu (37 million therms, 3.9 PJ).

EIA assumes that *hydrocarbon gas liquid* (category (3) above) consumed in the residential, commercial, and transportation sectors is propane (EIA, 2019). In practice, this fraction of the *hydrocarbon gas liquid* stream is liquefied petroleum gas (LPG), a mixture containing ~90% propane with the balance primarily butane and ethane. Combined, the three sector consumption of LPG totaled 3.3 trillion Btu (33 million therms, 3.5 PJ) in 2018 (EIA, 2020a). These data indicate that 2018 LNG and SNG consumption was on equal footing with LPG use on an energy basis.

LNG, SNG, and a fraction of the LPG used in the state are delivered to consumers by Hawaii Gas' underground pipelines. Those customers not served by pipelines receive LPG in bulk tanks of varying size. The method of delivery is the primary delineation between regulated (pipeline) and unregulated (bulk) gas sales (DCCA, 2021).

EIA totals can be compared with locally available data. The following is excerpted from the Annual Renewable Energy Report filed by Hawaii Gas in accordance with HRS 269-45, Gas Utility Companies Renewable Energy Report (HG, 2019).

"*Hawaii Gas' utility gas operations consist of the purchase, production, transmission, distribution, and sale of utility gas, which includes synthetic natural gas [SNG], renewable natural gas [RNG], propane, and liquefied natural gas [LNG], which are clean-burning fuels that produce significantly lower levels of carbon emissions than other hydrocarbon fuels, such as oil and coal. Hawaii Gas provides a safe, reliable, and economical source of energy to approximately 70,000 residential and commercial customers throughout the State, with almost half of those customers served by the utility system on Oahu.*

SNG is produced using naphtha, a byproduct or waste of the existing oil refining process in Hawaii, steam, water and hydrogen [in large part from recycled wastewater]." (HG, 2019)

Hawaii Gas reports that commercial customers (10% of their base) consume 85% of the gas and residential customers account for the balance (HG, 2021).

Hawaii Gas' Annual Renewable Energy Report (HG, 2019) also includes the following information related to their 2019 production:

- 905,837 barrels of imported oil saved by using SNG instead of electricity;
- 5,446,140 Btu per barrel of oil;
- For every 1 (one) barrel of therm equivalent SNG, it would require 2.813 barrels of oil for generator fuel.

Using this information and Equation (1) and noting that $E_{2019\ oil\ equivalent}$ is 2.813 times greater than E_{2019}, the energy content of Hawaii Gas' annual SNG sales from petroleum feedstock, E_{2019} was estimated at 27.2 million therms (2.87 PJ)[1]. This is comparable to the value of 32 million therms for "*natural gas* *including* *supplemental gas fuels*" reported by EIA (EIA, 2020).

$$E_{2019\,oil\,equivalent} - E_{2019} = E_{imported\,oil\,savings} \quad (1)$$

Also providing context for the report, Hawaii Gas reports producing 381,529 therms (0.04 PJ) of RNG from biogas at the Honouliuli wastewater treatment plant (WWTP).

2. Renewable natural gas production

Biological and thermochemical conversion routes to renewable natural gas are described below.

2.1 Biological conversion

Biological conversion processes typically occur under anaerobic conditions, where biogenic material (substrate) is consumed by a community of bacteria (anaerobes) in anoxic conditions. In the final step of the process, methane-producing (methanogenic) bacteria convert substrate to microbial biomass (i.e., via cell division) and metabolite biogas primarily composed of carbon dioxide (CO_2), and methane (CH_4). This conversion does not occur with 100% efficiency and some portion of the biogenic material will remain. CO_2 and CH_4 are gases at ambient temperatures and pressures, and the gas stream from an anaerobic process can be collected for beneficial use or disposal.

Anaerobic production of biogas occurs naturally in anoxic swampy areas and deep ocean sediments, the digestive tracts of ruminants, termites, and oceanic zooplankton (Karl and Tilbrook, 1994), and a number of common waste management techniques for high moisture materials, e.g., solid waste landfills and digesters designed to treat urban wastewater, livestock manure, or food wastes. Sealed landfills initially contain air, but the oxygen is quickly consumed by aerobic bacteria resulting in an anaerobic environment. Under these oxygen depleted conditions, a bacterial community dominated by anaerobes evolves and biogas production ensues. Modern landfills are designed with systems in place to extract and manage biogas with a lifetime overall recovery efficiency of about 75% (USEPA, 2008). Digesters are designed to create and maintain anaerobic conditions for treating and stabilizing waste so that it can safely be returned to the environment or beneficially reused. Digester systems are designed to contain, collect, and manage the biogas byproduct. The potential for materials to produce biogas in a digester system is dependent on the characteristics of the solid material, among other

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[1] U.S. customary units and International System (SI) units are included throughout the report, anticipating different preferences by prospective readership.

things. Solids content is characterized as total solids (TS) and volatile solids (VS), and the latter is the component that the anaerobic digestion process partially converts to biogas. Volatile solids are determined by dry sample weight loss at 550 °C (1,022 °F) in an oxidizing environment (i.e., Method 2540 G in Clesceri et al., 1998).

As noted, CO_2 and CH_4 are the principal components of biogas, but other compounds may be present depending on the substrate and the design and management of the landfill or digester system. Under the best conditions, CH_4 can account for up to 70% of the total gas volume with CO_2 as the balance. Under less favorable conditions, the biogas can contain measurable amounts of other compounds derived from the substrate, including moisture, ammonia, sulfur compounds, halogenated compounds, siloxanes, and volatile organic compounds. These compounds can delimit end-use applications, and may have negative impacts on materials, human health, and/or the environment; hence, they can be considered contaminants. Landfill gas collection and digester systems that are poorly sealed may also allow air intrusion, resulting in the presence of oxygen and nitrogen. When RNG is the targeted end product, oxygen (O_2), nitrogen (N_2), and CO_2 can be considered diluents. The presence of O_2 is of additional concern as it may result in mixtures that are above the methane flammability limit.

RNG is produced from biogas by removing contaminants and diluents (i.e., "upgrading") to achieve the gas quality required for a particular application. Fossil natural gas pipelines specify limits on the amounts of contaminants and diluents (e.g., <3 to 5% total inert gas content (i.e., CO_2, N_2, etc.), <0.2 to 0.4% O_2, <5.7 mg H_2S/m^3, etc.) and a range of acceptable values for the Wobbe Index (e.g., 1,279 – 1,385 Btu/scf (48-52 MJ/m^3)) and gas energy content (e.g., 950 to 1,150 Btu/scf (35-42 MJ/m^3)) (SoCalGas, 2011 & SoCalGas, 2017; see Appendix A). Note that pure methane has an energy content of 1,010 Btu/scf (38 MJ/m^3).

2.2 Thermochemical Conversion

Gasification is the primary thermochemical conversion process that can be used to synthesize RNG (sometimes call synthetic RNG or SRNG). Figure 1 presents a schematic diagram of the thermochemical RNG production process. Gasification is the partial oxidation of biomass (wood, bagasse, regionally available fiber materials, etc.) to form a combustible gas. The goal of the gasification process is to simultaneously maximize the solid fuel carbon conversion and the energy content of the product gas. Air, steam, oxygen, or mixtures of these gases can be used as oxidation agents. The gasification process occurs at temperatures ranging from ~1,300 to 2,200 °F (700 to 1,200 °C). When oxygen or air is used to create the heat needed to drive the thermochemical process, oxidizer is limited to ~30% of that needed to support complete combustion. Feedstocks for thermochemical gasification are typically required to have ≤10% moisture content (wet basis). Conversion of carbon present in the fuel should approach 95%. The product gas contains primarily carbon monoxide (CO), CO_2, hydrogen (H_2), and CH_4. Particulate matter and other compounds will be present as contaminants and the latter may include higher hydrocarbons (C_2+ and both permanent gases and condensable species), ammonia, hydrogen cyanide, hydrogen sulfide, carbonyl sulfide, thiophene, oxides of nitrogen, chlorides, and other inorganic species. Contaminant pose hazards to materials (e.g., catalysts, heat exchanges surfaces, etc.), human health, and/or the environment. To produce RNG from the product gas, contaminants must be reduced to acceptable levels, the ratio of CO, CO_2, and H_2 must be adjusted (gas conditioning), and then CO and CO_2 are reacted with H_2 to form additional CH_4 (synthesis/methanation). The methane rich product gas from the synthesis step is upgraded to meet specifications required by the RNG offtaker.

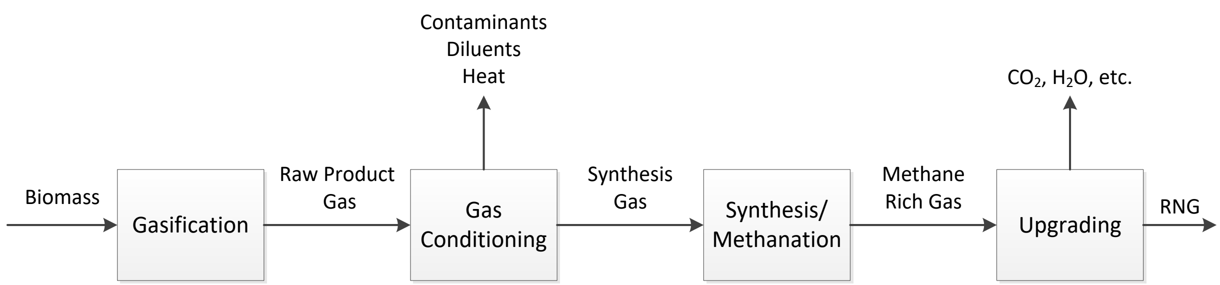

Figure 1. Thermochemical production of RNG from biomass (adapted from Williams et al., 2014).

3. Biomass resources for production of RNG

Biomass resources for biological and thermochemical conversion processes in Hawaii are summarized in the following sections.

3.1 Biomass resources for biological conversion

Biomass resources in Hawaii that could be used for RNG production via biochemical pathways include animal manure, biosolids/activated sludge at waste water treatment plants, and biogenic components of municipal solid waste (MSW) disposed in landfills.

3.1.1 Livestock manure

Inventories of hogs, cattle and calves, and poultry in Hawaii are summarized in this section. Data on the size and number of farms and the inventory of animals on farms can be used to identify opportunities where sufficient manure may be produced to justify onsite anaerobic digestion. Waste management may be a necessary component of a livestock production facility. The Environmental Protection Agency's National Pollutant Discharge Elimination System (NPDES) uses the following two criteria to identify animal feeding operation (AFO):

- "Animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and;
- Crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility."

Note that this classification does not apply to aquatic animal production facilities. A concentrated animal feeding operation (CAFO) meets the criteria of an AFO and is classified according to the information in Appendix B, *Regulatory Definitions for Large CAFOs, Medium CAFOs and Small CAFOs*. CAFOs are regulated under the NPDES permitting program and may be candidates for manure management using anaerobic digestion. CAFOs are not present in Hawaii, according to Dr. C.N. Lee, University of Hawaii, Animal Science Extension Specialist (Lee, 2020). The 2017 animal population data from the 2019 USDA (NASS, 2019) census of agriculture (Appendix B) are summarized in the following sections.

Hogs

Table 1 presents available 2017 data on non-feral hog populations in Hawaii (NASS, 2019). Although it is not possible to arrive at a total number of hogs in the state from these data, it is possible to estimate that the population is at least 8,500 head. The State of Hawaii data book (DBEDT, 2019) documents declining hog production over the past 20 years, with populations in 1997, 2007, and 2017, of 29,000, 15,000, and 8,000, respectively. The number of farms with hogs during the 2007 to 2017 period has remained relatively constant at ~225, indicating that the decline in hog population has likely been due to the loss of larger producers.

Using values for USDA estimates for hog manure production (154 lb average weight, 5.4 lb volatile solids/d/1,000 lb animal unit, as-excreted basis) (NRCS, 2008) and methane production from anaerobic digestion (350 L/kg of volatile solids or 5.6 ft^3/lb volatile solids) (Chae et al., 2008), the annual potential production of RNG from the Hawaii swine population is estimated to ~147,000 therms per year (14,665,000 ft^3 per year or 15,500 GJ/y). Note that this is an estimate of potential only, and this value does not reflect what would occur in practice. Production scale (farm size and anaerobic digester (AD) volume), siting considerations, waste collection and management system design, operation, and maintenance all affect actual productivity.

Table 1. Summary of swine populations and hog farm sizes in Hawaii, 2017 data (NASS, 2019).

Head Count	Hawaii		Honolulu		Kauai		Maui		State	
	Farms	Hogs	Farms	Hogs	Farms	Hogs	Farms	Hogs	Farms	Hogs
1 - 24	71	205	13	56	12	107	70	445	166	813
25-49	4	(D)	3	(D)	8	258	1	(D)	16	570
50-99	5	290	1	(D)	4	(D)	1	(D)	11	688
100-199	12	1,290	6	740	0	0	7	928	25	2,958
200-499	1	(D)	4	(D)	0	0	1	(D)	6	2,039
500-999	0	0	1	(D)	0	0	0	0	1	≥ 500
1,000<	0	0	0	0	1	(D)	0	0	1	≥ 1,000
Total	93	2,252	28	(D)	25	(D)	80	1,831	226	≥ 8,568

Note: (D) -- Withheld to avoid disclosing data for individual farms

Cattle

Cattle production in Hawaii is focused on beef production rather than dairy and is carried out largely on pasture. The 2017 agricultural census data for cattle production in Hawaii is presented in Table 2 (NASS, 2019). The number of animals across the state totaled ~138,000. Melrose et al. (2015) reported pasture acreage by island that totaled ~760,000 acres (~308,000 ha) across the state. Using these data, average pasture stocking rates of ~0.18 animals per acre (~5 acres per animal, 2 ha per animal) can be calculated. Although it is a generalization that may not reflect management practices of individual producers, the low stocking rate suggests that collecting beef cattle waste for RNG feedstock is not practical under current production practices.

Poultry

Poultry production in Hawaii is focused on chickens that produce eggs. Data show that in 2017, this subcategory accounted for 84% of the total poultry population (228,912 birds) of the state (NASS, 2019). Table 3 summarizes the layer population and farm size data for Hawaii. Based on the layer population of the state and a daily production value of 0.036 lb (16 g) volatile solids per animal per day, the annual manure resource relevant to anaerobic digestion is ~1,260 tons (1,140 Mg) of volatile solids per year. The use of poultry manure in anaerobic digesters is limited by its high nitrogen content and low moisture content (Rodriguez-Verde et al., 2018) and these properties may encourage its use as fertilizer. Nonetheless, based on the same set of assumptions used above to estimate RNG potential for hog manure, the annual potential production of RNG from the Hawaii poultry population is estimated to ~142,000 therms per year (14,188,000 ft^3 per year or 15,000 GJ/y). Note that Rodriguez-Verde et al. (2018) determined that CH_4 yield from digested poultry manure was ~45% of the yield from hog manure, but were able to achieve comparable yields by pretreating or blending the poultry waste. As such, attaining this estimated RNG potential in practice would require additional management compared to hog, wastewater, or food waste based systems described elsewhere in this report. Production scale (farm size and AD volume), siting considerations, waste collection and management system design, operation, and maintenance all factor into actual productivity.

Table 2. Summary of cattle and calf populations and farm sizes in Hawaii, 2017 data (NASS, 2019).

Head Count	Hawaii		Honolulu		Kauai		Maui		State	
	Farms	Cattle	Farms	Cattle	Farms	Cattle	Farms	Cattle	Farms	Cattle
1 - 9	443	1,854	22	61	44	211	90	349	599	2,475
10-19	101	1,383	1	(D)	16	(D)	45	603	163	2,219
20-49	111	3,163	4	116	26	795	24	708	165	4,782
50-99	51	3,752	2	(D)	20	(D)	9	688	82	5,939
100-199	61	8,424	11	1,293	9	1,258	8	1,050	89	12,025
200-499	46	14,402	5	1,851	10	2,932	7	1,829	68	21,014
500<	34	65,873	1	(D)	7	(D)	10	13,864	52	89,476
Total	847	98,851	46	4,984	132	15,004	193	19,091	1,218	137,930
Pasture										
(acres)	554,300		18,400		41,900		108,400		761,200	
(hectares)	224,300		7,400		17,000		43,900		308,000	
Average stocking density										
(head/acre)	0.18		0.27		0.36		0.18		0.18	
(head/hectare)	0.44		0.67		0.89		0.44		0.44	

Note: (D) -- Withheld to avoid disclosing data for individual farms

Table 3. Summary of poultry populations and farm sizes in Hawaii, 2017 data (NASS, 2019).

	Hawaii		Honolulu		Kauai		Maui		State	
	Farms	Head	Farms	Head	Farms	Head	Farms	Head	Farms	Head
All Poultry	410		97		48		211		766	228,912
Layers										
1-49	326		58		39		172		674	
50-99	14		7		5		15		41	
100-399	22		3		1		3		29	
400-3,199	0		0		0		6		6	
3,200-9,999	0		1		0		0		1	
10,000-19,999	0		1		0		0		1	
20,000-99,999	0		0		0		0		0	
100,000<	0		1		0		0		1	
Layer Total	362	7,999	71	(D)	45	1,059	196	(D)	674	192,185

Note: (D) -- Withheld to avoid disclosing data for individual farms

3.1.2 Wastewater Treatment Plants

Hawaii currently has ~190 wastewater treatment plants (WWTPs), including both public and private facilities serving communities or properties with multi-dwelling units. This does not include cesspools or septic tanks (on site disposal systems) serving individual properties which number more than 100,000 across the state. The number and scale (average daily flow) of WWTPs are summarized in Figure 2. Table 4 summarizes information on treatment plants that receive more than one million gallons of wastewater per day. Three WWTPs on Oahu, Sand Island, Honouliuli, and Kailua, receive volumes in excess of 15 million gallons per day (gpd) (~57,000 m^3d^{-1}). Sand Island, serving central Honolulu, is the largest and treats ~76 million gpd (~290,000 m^3d^{-1}). WWTPs that treat between 1 and 5 million gpd (~3,800 – 18,900 m^3d^{-1}) include East Honolulu, Waianae, and Schofield on Oahu; Lahaina, Wailuku-Kahului, and Kihei on Maui; Hilo and Kealakehe on Hawaii; and Lihue on Kauai. With the exception of East Honolulu and Schofield, all are public, county-owned facilities.

Sand Island, Honouliuli, Kailua, East Honolulu, Waianae, Schofield, Hilo, and Lihue WWTPs operate anaerobic digesters to stabilize sludge from the treatment process prior to final disposal (combustion or landfill). Table 4 also summarizes available data on final sludge generation rate, biogas generation rate, methane content of biogas, and potential RNG production amounts.

RNG is currently produced from biogas generated by the Honouliuli WWTP digester. Hawai`i Gas (https://www.hawaiigas.com/) installed a biogas upgrading facility at the site with a reported capacity of ~800,000 therms of RNG per year (80 million ft^3 per year or 84.4 TJ). During its first year of operation, Hawaii Gas reported producing 381,529 therms (38,153,000 ft^3, 40.3 TJ) of RNG at Honouliuli (HG, 2020). A more common use of biogas at WWTPs is to combust it and use the heat to increase the temperature of the anaerobic digesters to improve digester performance, i.e., increase volatile solids destruction and biogas production. Sand Island also reports biogas use for process heat to dry biosolids pellets. Where RNG production or digester heating are not practiced, the biogas is flared, i.e. controlled combustion with air to produce carbon dioxide and water. Methane has a global warming potential 25 times greater than CO_2, and disposal in a flare provides an environmental benefit when the alternative is direct release of the biogas to the atmosphere.

Complete methane production data from all of the larger WWTPs shown in Table 4 were not available. Using the combined methane production values and the wastewater flow rates from the Sand Island, Honouliuli, Waianae, East Honolulu, and Schofield WWTPs, a production factor of ~3,831 ft^3 CH_4 per million gallon wastewater (28.7 m^3 CH_4 per 1,000 m^3 of wastewater) was calculated. Applying this to the total volume of wastewater at WWTPs with anaerobic digestion listed in Table 4, the gross statewide RNG potential from WWTPs is estimated to be 513,000 ft^3 CH_4/day (~1.9 million therms per year or 200 TJ y^{-1}).

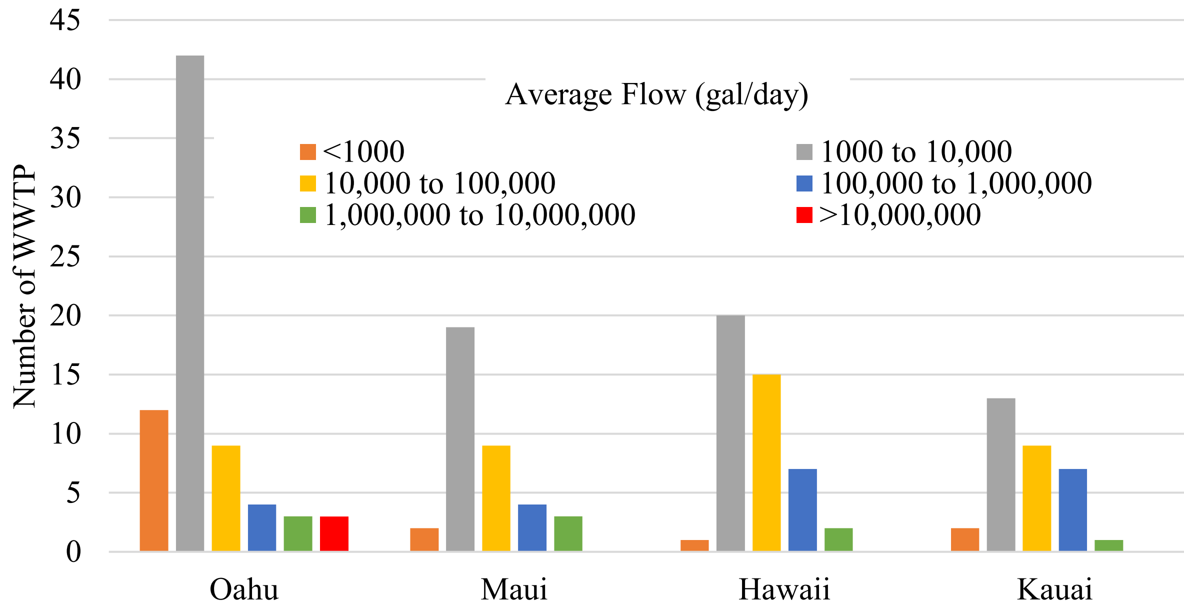

Figure 2. Wastewater treatment plant size distribution by county.

Table 4. Salient characteristics of WWTPs in Hawaii receiving daily wastewater flows greater than 1 million gallons per day.

Name	County/ Ownership	Wastewater Received[a] (average million gpd)	Anaerobic Digester	Biogas Production (ft^3/day)	Methane Concentration (%)	Methane Production (ft^3/day)	Methane Production (therms/y)	Biogas Use[c]
Sand Island	Honolulu/public	76.0	Yes	337,888	60 (assumed)	202,733	739,975	C, D
Honouliuli	Honolulu/public	25.7	Yes	300,000	60	180,000	657,000	B, C, D
Kailua	Honolulu/public	16.3	Yes	104,000[b]	60 (assumed)	62,446[b]	227,926[b]	C, D
Waianae	Honolulu/public	3.8	Yes	28,000	50 to 70	16,800	61,320	D
East Honolulu	Honolulu/private	4.4	Yes	37,000	57	21,090	76,979	D
Schofield	Honolulu/private	2.4	Yes	16,000	60	9,600	35,040	C, D
Lahaina	Maui/public	4.2	No	na	na	na	na	na
Wailuku-Kahului	Maui/public	3.9	No	na	na	na	na	na
Kihei	Maui/public	3.6	No	na	na	na	na	na
Hilo	Hawaii/public	4.2	Yes	27,000[b]	60 (assumed)	16,090[b]	58,729[b]	D
Kealakehe	Hawaii/public	1.7	No	na	na	na	na	na
Lihue	Kauai/public	1.1	Yes	7,000[b]	60 (assumed)	4,214[b]	15,382[b]	D

[a] Source, Wastewater and Clean Water Branches, Department of Health, State of Hawaii

[b] Assumes 3,831 ft^3 CH_4 per million gal WW based on the averaged operating data from Sand Island, Honouliuli, Waianae, East Honolulu, and Schofield WWTPs

[c] B – RNG (Hawaii Gas), C – combusted for process heat (e.g. biosolids drying or digester heating), D – balance flared

See Appendix H for SI unit version of this table

3.1.3 Landfill Gas

The State of Hawaii has 14 landfills, seven of which are closed and no longer receiving waste (Table 5). The most recent closure was the South Hilo Sanitary Landfill at the end of 2019. Six landfills have gas collection systems in place and produce LFG ranging from 0.055 to 1.13 million standard cubic feet per day (mmscfd) (1,560 to 32,000 m^3d^{-1}). In all cases, collected LFG is flared.

Five landfills in the state are identified by US EPA's Landfill Methane Outreach Program (LMOP, 2020) as energy project candidates; for additional information see Appendix D. Table 6 summarizes information relevant to RNG resources from the six MSW landfills in Hawaii that have LFG collection systems installed with corresponding historic annual methane production values presented in Figure 3. LFG resources and RNG potential are discussed below.

Maui

The data show that Central Maui Landfill is the largest producer of LFG, has the highest methane concentration (52%), and has had an upward trend in production volume from 2010 to 2018, averaging a 9% annual increase. Central Maui's production potential in 2018 was 215 million scf RNG per year (2.15 million therms per year or 227 TJ).

Oahu

Waimanalo Gulch Landfill & Ash Monofill on Oahu produced slightly more than 1 million scf LFG per day (28,300 m^3d^{-1}) in 2019. Coupled with methane concentration (47.3%) data yields production potential of 177 million scf RNG per year (1.77 million therms per year or 187 TJ). Note, however, the downward LFG production trend at Waimanalo Gulch since 2015 due to increased recycling rates and the addition of a third boiler at the HPOWER waste to energy facility in 2012 (Opala808, 2012). This trend would be expected to continue as the inventory of biogenic waste in place at Waimanalo Gulch declines due to decomposition and lower rates of addition of new material due to diversion to HPOWER.

Kauai

The Kekaha Phases I&II landfill on Kauai produced ~630,000 scf of LFG per day (17,800 m^3d^{-1}) in 2019. Reported methane concentrations in 2018 were ~43%, indicating potential production of 98 million scf RNG per year (0.98 million therms per year, or 103 TJ). The LFG collection system was installed at Kekaha in 2016 (Cornerstone, 2015) and the upward trend in LFG production data may be due in part to improved management of the system over time.

Table 5. Summary of 2018 data on landfills in the State of Hawaii (LMOP, 2020).

Landfill Name	Landfill Owner Organization(s)	Year Opened	Closure Year	Current Status	Waste in Place (tons)	Waste in Place Year	LFG Collection System In Place?	LFG Collected[a] (million scf/day)	LFG Flared[a] (million scf/day)	Current LFG Project Status [b]
Central Maui	Maui County	1987	2039	Open	5,412,118	2018	Yes	1.133	1.133	Candidate
Hana Landfill	Maui County	1969	2079	Open	124,500	2008	No			FP
Kailua Landfill	Hawaii County	1975	1993	Closed	500,000		No			LP
Kalamaula Landfill	Maui County	1970	1993	Closed	81,625	1993	No			LP
Kaneohe MC Air Station Landfill	United States Marine Corps	1978	2024	Open			No			Unknown
Kapaa	C&C of Honolulu	1955		Closed	4,500,000	2000	?			LP
Kapaa and Kalaheo Sanitary Landfills	C&C of Honolulu	1970	1995	Closed	5,838,786	1995	Yes	0.396	0.396	Shutdown
Kekaha Phases I & II	County of Kauai	1953	2021	Open	2,759,422	2018	Yes	0.629	0.629	Candidate
Lanai Landfill	Maui County	1969	2020	Open	182,910	2008	No			FP
Naiwa Landfill, Molokai	Maui Co	1993		Open	90,800	2008	No			FP
Olowalu Landfill	Maui County	1967	1992	Closed	259,700	1992	No			LP
Palailai Landfill	Grace Pacific Co.	1974	1988	Closed	2,845,215	1988	Yes	0.055	0.055	LP
South Hilo Sanitary Landfill (SHSL)	Hawaii County	1969	2020	Open	3,133,012	2018	No			Candidate
Waimanalo Gulch Landfill & Ash Monofill	C&C of Honolulu	1989	2038	Open	12,161,011	2018	Yes	1.027	1.027	Candidate
West Hawaii Landfill/Pu`uanahulu	Hawaii County	1993	2054	Open	2,651,566	2018	Yes	0.38	0.38	Candidate

[a] LFG volume reported at 60 °F (15.6 °C) and 1 atm pressure

[b] The LMOP website "defines a candidate landfill as one that is accepting waste or has been closed for five years or less, has at least one million tons of waste, and does not have an operational, under-construction, or planned project; candidate landfills can also be designated based on actual interest by the site." FP = Future Potential, LP = Low Potential

See Appendix H for SI unit version of this table

Table 6. Estimate of LFG methane resource at landfills with collection systems.[a]

Landfill Name	CH_4 concentration in LFG (volume %)[a]	Volume of CH_4 [a]		Energy Content of CH_4	
		(million scf y^{-1})	(million m^3 y^{-1})	(million therms y^{-1})	(TJ y^{-1})
Central Maui Landfill	52	215	6.1	2.15	227
Kapaa and Kalaheo Sanitary Landfills	42.3	61	1.7	0.61	64
Kekaha Landfill/Phases I & II	42.9	98	2.8	0.98	103
Palailai Landfill	40.8	8	0.23	0.08	8.4
Waimanalo Gulch Landfill & Ash Monofill	47.3	177	5.0	1.77	187
West Hawaii Landfill/Puuanahulu	41.65	58	1.6	0.58	61
State Total	-	617	17.5	6.17	651

[a] 2018 LFG methane concentration and volume data, source EPA GHG reporting program (USEPA, 2018)

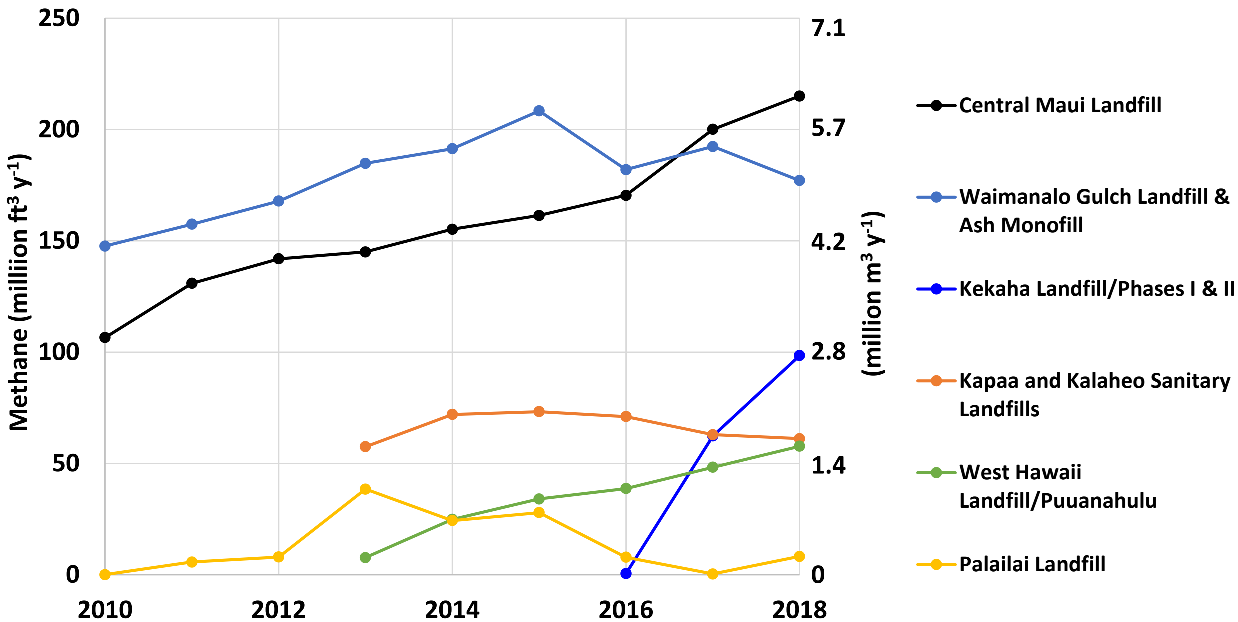

Figure 3. Annual methane production at Hawaii landfills with LFG systems installed.

3.1.4 Food Waste

Food waste includes kitchen trimmings, plate waste and uneaten prepared food from restaurants, cafeterias, and households as well as unsold and spoiled food from stores and distribution centers and loss and residues from food and beverage production and processing facilities (USEPA, 2020). The City & County of Honolulu defines food waste as "all animal, vegetable, and beverage waste which attends or results from the storage, preparation, cooking, handling, selling or serving of food. The term shall not mean commercial cooking oil waste or commercial FOG waste" (C&C, 2020, see Appendix E).

The US generates approximately 63 million tons (57.1 million Mg) of food waste per year (Table 7) which represents one-third of the total food supply (USDA, 2014).

Table 7. Annual food waste estimates for the U.S.

Source	Generated		Per Capita		Data Year
	(million tons y^{-1})	(million Mg y^{-1})	(lb ca^{-1} y^{-1})	(kg ca^{-1} y^{-1})	
USEPA (2020)	63	57.1	385	175	2018
USDA (2014)	66.4	60.2	429	195	2010
Buzby (2012)	62.9	57.1	414	188	2008
ReFED (2016)	63	57.1	393	178	2015

Management practices (or fate) include using food waste for animal feed (as appropriate), or feedstock for compost or anaerobic digestion processes; or sending it to landfill or combustion facilities. In the US, 43 – 52 million tons (39 – 47 million Mg) of food waste (68 – 83% of the estimated total mass) are landfilled or disposed in combustion facilities (USEPA 2020, ReFED 2016).

Food Waste in Hawaii

Estimates for annual food waste generation in Hawaii range from 163,000 tons (147,800 Mg) in 1999 (Belt Collins Hawaii, 2000) to 370,000 tons (335,600 Mg) (Okazaki et al., 2008) (Table 8). Per capita food waste estimates in Table 8 range from 244 to 529 lb/ca/y (111 – 240 kg ca^{-1} y^{-1}). The average of these Hawaii-based per-capita food waste estimates is 344 lb/ca/y (156 kg ca^{-1} y^{-1}), significantly lower than the U.S. value, ~400 lb/ca/y (180 kg ca^{-1} y^{-1}).

Table 8. Annual food waste estimates for Hawaii.

Source	Generated (tons/y)	Per Capita (lb/ca/y)	Recycled (tons/y)	% Recycled	Defacto Population	Data Year	Comments
Belt Collins Hawaii (2000)	162,600	244	15,319	9.4	1,332,000	1999	Household and businesses
Turn et al. (2002)	179,300	265			1,353,000	2002	Household and businesses
Okazaki et al. (2008)	370,200	529	95,156	25.7	1,400,000	2005	Food Establishments
Loke & Leung (2015)	248,800	339			1,468,000	2010	Consumer, Distr., retail

See Appendix H for SI unit version of this table

Food waste management in the state currently includes animal feed (in-state hog farms and some export to the continental US), feedstock for in-state biodiesel production (yellow grease), home-based composting, and disposal to landfill or combustion (on Oahu) (Okazaki et al., 2008; B&V, 2010; Cornerstone, 2015; Turn et al., 2002).

Food waste currently landfilled in Hawaii is a potential resource for renewable natural gas (via anaerobic digestion). State wide, currently disposed food waste totals could support production of about 515 million ft^3 per year (14.6 million m^3 y^{-1} or 5.15 million therms per year) of methane production via anaerobic digestion (Table 9).

Available data for solid waste composition and disposal practices from each county's Integrated Solid Waste Management Plan (ISWMP) and the State Office of Solid Waste Management annual reports to the legislature were reviewed. Summaries for the four counties are presented below (see Appendix F for waste characterization data used for each county).

City & County of Honolulu

A mandatory food waste recycling ordinance has been in place on Oahu since 1997. Food waste recycling on the island has averaged nearly 40,000 tons (36,300 Mg) per year for the past twenty years, partly due to the recycling ordnance, as well as the existence of viable alternatives that include feed for local hog farms, on-island biodiesel production and distribution to food banks of "expired" but still edible food (Loke and Mak, 2018; B&V, 2010; Turn et al., 2002).

About 35% of MSW generated on Oahu is recycled. Of the remainder, approximately 90% is sent to the H-POWER combustion facility and the rest to the Waimanalo Gulch Sanitary Landfill (WGSL) (Honolulu, City & County, 2019 & 2020).

Based on recent and projected waste disposal on Oahu, and waste composition, about 9,700 tons (8,800 Mg) of food waste in the MSW stream was landfilled in 2020 (Towill & SMS, 2017; Cascadia, 2018; Honolulu, City & County, 2020). This would support production of about 53 million ft^3 per year (1.5 million m^3 y^{-1} or 0.53 million therms per year) of methane production, assuming 50% of the food waste is recoverable for use as feedstock in anaerobic digestion (Charbonnet et al., 2019; Fitamo et al., 2016) (Table 9).

County of Maui

The county of Maui encompasses Lanai, Molokai, and Maui Islands. More than 95% of the county's solid waste generation and disposal occurs on Maui (GBB, 2008). Some 32,000 tons (29,000 Mg) of food waste is landfilled in Maui County which could support about 180 million ft^3 per year (5.1 million m^3 y^{-1} or 1.8 million therms per year) of methane production (Table 9)

County of Kauai

About 9,500 tons (8,600 Mg) of food waste is landfilled in Kauai based on a 2016 waste characterization and 2015-2019 solid waste disposal amounts (Cascadia, 2017; OSWM, 2016; OSWM, 2020). This could support about 53 million ft^3 per year (1.5 million m^3 y^{-1} or 0.53 million therms per year) of methane production (Table 9)

County of Hawaii

The County of Hawaii is in the process of closing the South Hilo Landfill and all solid waste is now disposed at the West Hawaii Sanitary Landfill. About 41,000 tons (37,200 Mg) of food waste is landfilled in Hawaii County based on a 2008 waste characterization study and 2019 disposal data (ISWMP by Parametrix, 2019; OSWM, 2020). This could support about 230 million ft^3 per year (6.5 million m^3 y^{-1} or 2.3 million therms per year) of methane production (Table 9).

Table 9. County food waste disposal and associated methane potential via AD by county.

	2015	2019
Maui ISWMP (2008), OSWM (2016), OSWM (2020)		
Landfill Disposal (tons, MSW including food waste)	183,167	223,321
Food Waste Disposal (tons)	26,501	32,310
Food Waste Recovered for AD (tons, assume 50% recovery)	13,250	16,155
Potential CH_4 production from AD (million scf CH_4 per year) *	147	179
Potential CH_4 production from AD (million therms CH_4 per year)	1.47	1.79
Kauai 2016 Waste Characterization (2008), OSWM (2016), OSWM (2020)		
Landfill Disposal (tons, MSW including food waste)	81,500	92,082
Food Waste Disposal (tons)	8,411	9,503
Food Waste Recovered for AD (tons, assume 50% recovery)	4,206	4,752
Potential CH_4 production from AD (million scf CH_4 per year) *	47	53
Potential CH_4 production from AD (million therms CH_4 per year)	0.47	0.53
Hawaii County ISWMP & 2008 Waste Characterization (2008), OSWM (2016), OSWM (2020)		
Landfill Disposal (tons, MSW including food waste)	179,033	253,361
Food Waste Disposal (tons)	29,182	41,298
Food Waste Recovered for AD (tons, assume 50% recovery)	14,591	20,649
Potential CH_4 production from AD (million scf CH_4 per year) *	162	229
Potential CH_4 production from AD (million therms CH_4 per year)	1.62	2.29
Honolulu- City & County ISWMP & 2017 Waste Characterization		
Landfill Disposal (tons, MSW including food waste)	64,103	48,644
Food Waste Disposal (tons)	12,890	9,782
Food Waste Recovered for AD (tons, assume 50% recovery)	6,445	4,891
Potential CH_4 production from AD (million scf CH_4 per year) *	71	54
Potential CH_4 production from AD (million therms CH_4 per year)	0.71	0.54
Combined (Maui, Kauai, Hawaii, Honolulu)		
Landfill Disposal (tons, MSW including food waste)	507,803	617,408
Food Waste Recovered for AD (tons, assume 50% recovery)	38,492	46,447
Potential CH_4 production from AD (million scf CH_4 per year) *	427	515
Potential CH_4 production from AD (million therms CH_4 per year)	4.27	5.15

* Assumes food waste is 70% moisture, volatile solids comprise 85% of total solids, and specific gas production of 11,089 scf CH_4 / ton volatile solids (Charbonnet et al., 2019; Fitamo et al., 2016).

See Appendix H for SI unit version of this table.

3.1.5 Buffer zone around new or modified waste facilities

Recently enacted legislation in Hawaii prohibits siting a new, modified, or expanded waste or disposal facility in a conservation district or within ½ mile (0.8 km) of a residential, school, or hospital property line (SB2386 SD2 HD2, 30th Leg., Reg. Sess. (2020)). The "buffer" law does not apply to currently operating facilities, such as a landfill, unless and until the facility undergoes a modification (such as expansion) that requires additional permitting or permit modification.

It appears that transfer stations and facilities that would convert components of MSW to RNG, such as food waste anaerobic digesters or non-incineration thermal conversion, are included under the definition of "waste facility" or "solid waste reduction facility" under sections 340A-1 and 343G-1 of the Hawaii Revised Statutes (HRS 2021) and would require the ½ mile buffer.

Figure 4 shows conservation districts and half mile buffers around residential, school, and hospital properties in Hawaii. Figure 5 depicts total land area as either "restricted" by SB2386 from landfill or waste facility placement, or "unrestricted." About 82% of Oahu's land area, or ~314,000 acres (127,000 ha), is restricted leaving about 68,000 unrestricted acres (27,500 ha).

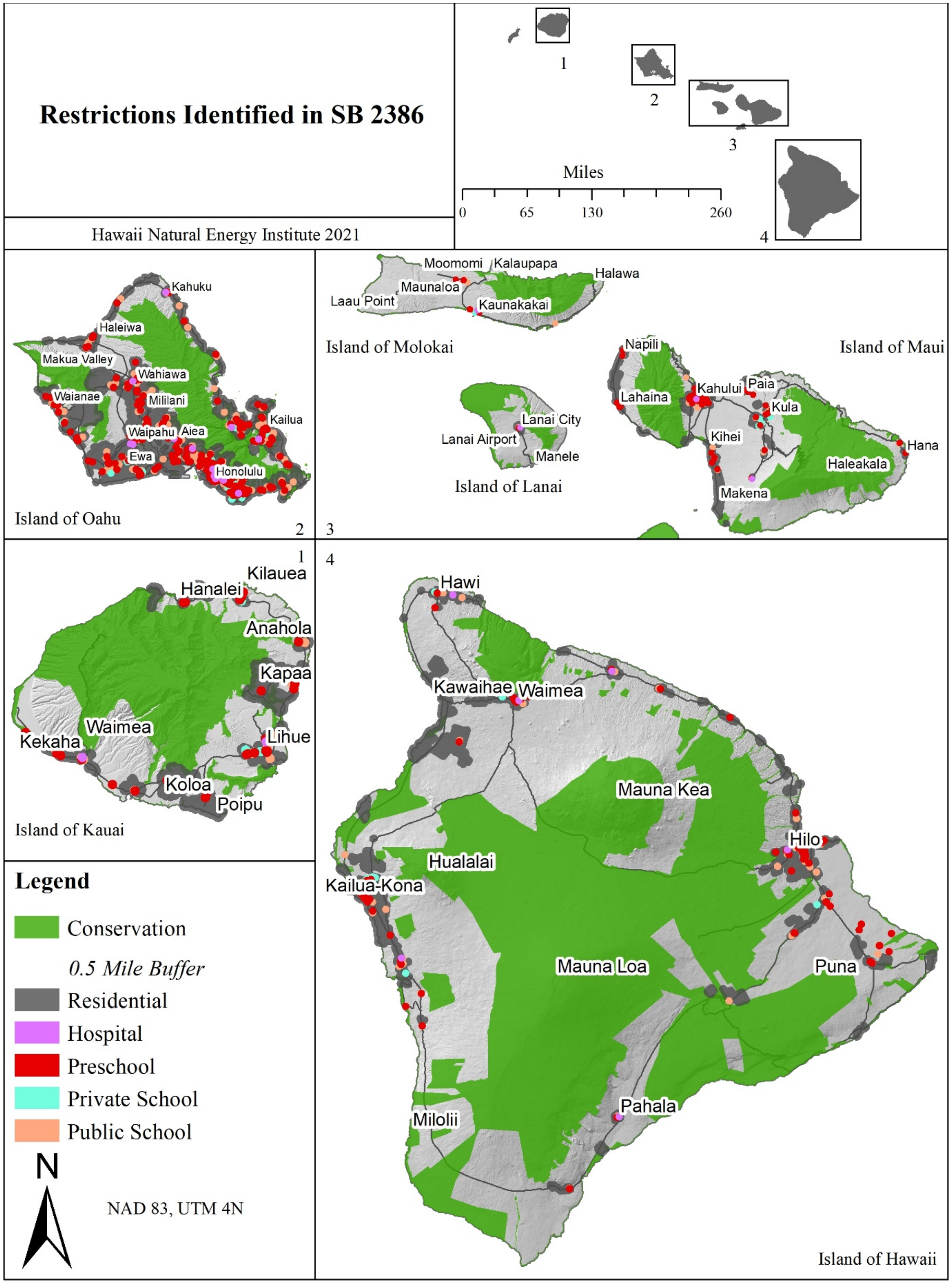

Figure 4. Conservation districts and half mile buffers around residential, school, and hospital properties.

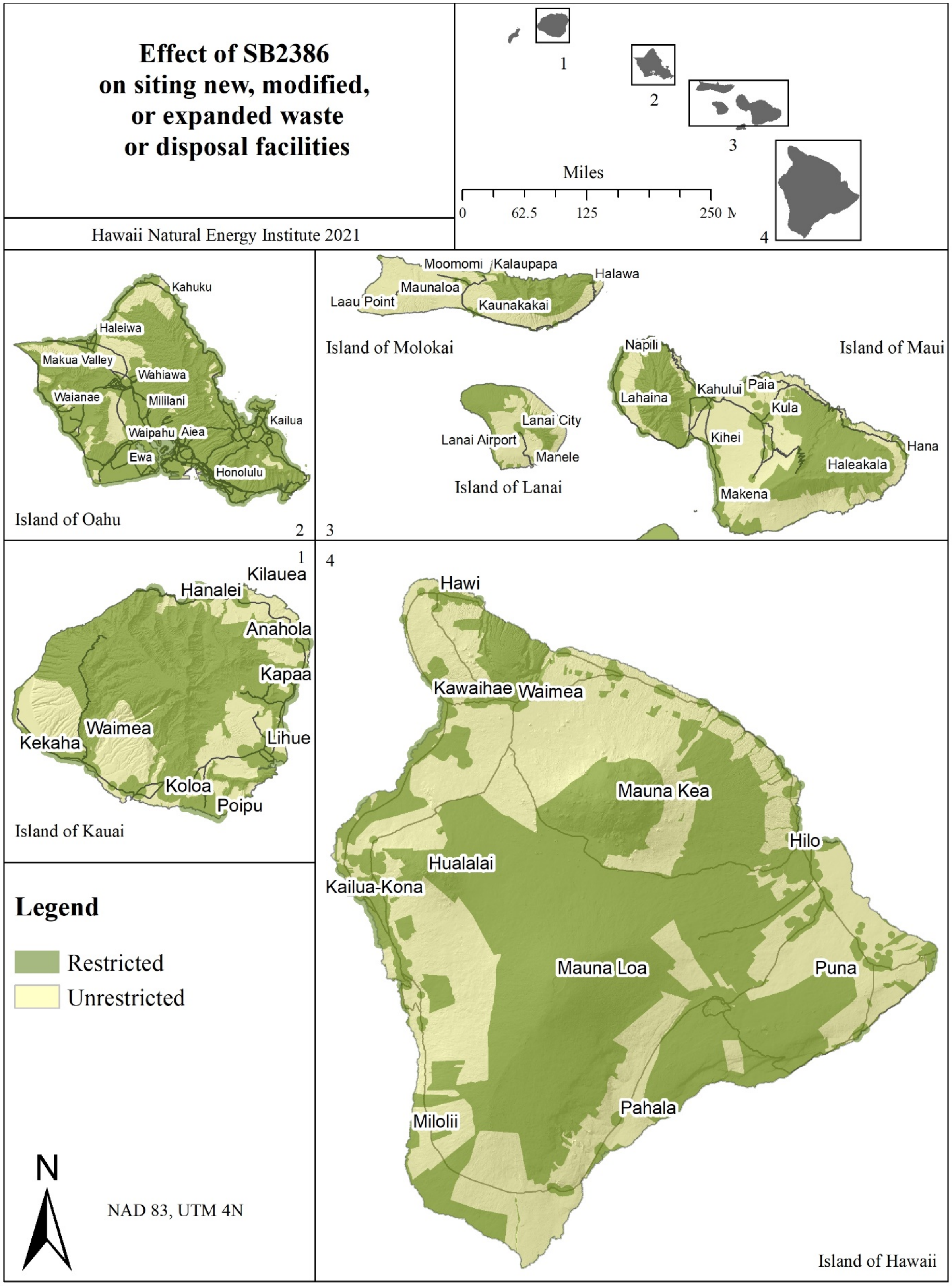

Figure 5. SB2386 restricted and unrestricted land.

3.2 Thermochemical RNG resources

RNG production using thermochemical gasification will rely on the availability of biomass fiber resources. These could include urban solid waste, agricultural or forestry residues, and purpose - grown energy crops. The latter, also referred to as dedicated feedstock supply systems, include fast growing grasses or trees that are cultivated for the sole purpose of supplying fiber to an energy conversion facility. Fiber resources are reviewed in the following sections.

Whereas methane generation and RNG potential at WWTP's and landfills are outcomes of (i.e., depend on) the amounts of waste handled and management, an advantage of thermochemical production is that it can be scaled to fit the demand for RNG, within the limitation of available fiber resources. Fiber resources can be transported and combined to increase conversion facility capacity. A recent study (GTI, 2019) evaluated thermochemical RNG production in California from a mixture of forest waste, demolition wood waste, and orchard residuals and can provide context for system scales. In summary, the facility design:

- assumed operation for 7,884 hours per year (90% availability);
- required a biomass flow rate of 33 tons of dry biomass per hour (785 tons per day, 258,000 tons per year) (29.9 dry Mg h^{-1}, 712 Mg d^{-1}, 234,000 Mg y^{-1});
- produced RNG with an energy content of 978 Btu per standard cubic foot (36.4 MJ m^{-3});
- produced RNG at a rate of 8.7 million standard cubic feet per day (2.9 billion standard cubic feet per year, 28 million therms per year) (82 million m^3 y^{-1}, 2,950 TJ y^{-1}).

The biomass feedstock requirement, 258,000 tons dry biomass per year (234,000 Mg y^{-1}), can be compared with recent fiber production in the Hawaii sugar industry. Hawaiian Commercial & Sugar Co. reported bagasse production of 591,000 tons (536,000 Mg) in 2003 (Jakeway et al., 2004). Accounting for bagasse moisture content (50% wet basis), this value is equivalent to 295,000 tons (267,600 Mg) of dry fiber annually. Note that the fiber was a byproduct of raw sugar production and not the primary product. Kinoshita et al.'s (1995) evaluation of a dedicated fiber production system on the island of Oahu as part of integrated resource planning exercises estimated production of 260,000 tons (235,800 Mg) of dry fiber annually on 12,000 acres (4,860 ha). These comparisons indicate that a thermochemical gasification facility of the scale described in the GTI study is consistent with possible fiber resources in Hawaii. The conversion facility processed 258,000 ton (234,000 Mg) per year and produced 28 million therms (2,950 TJ) per year, comparable to the 27.2 million therms (2,870 TJ) of annual utility gas sales estimated in the introduction of this report. Thermochemical gasification plants of smaller scale could also be considered.

3.2.1 Urban solid waste fiber resources

Urban waste fiber resources include materials disposed as municipal solid waste (MSW) and construction and demolition waste (CDW).

The fibrous and/or combustible portion of MSW include the drier, non-food biomass components of the waste stream (paper, cardboard, woody material, and green waste), textiles, and plastics (fossil or non-renewable carbon components).

Based on the same data for solid waste composition and disposal amounts used in the food waste discussion earlier, disposal and RNG potential from the fibrous/combustible portion of the MSW stream is shown for each county in Table 10. RNG potential from this resource ranges from 3.8 million therms (400 TJ) per year on Oahu to 18.9 million therms (2,000 TJ) per year on Hawaii. (see Appendix G for a comprehensive table that includes component moisture and energy content, wet and dry disposal amounts and RNG potential).

Table 10. Annual landfilled, and RNG potential, of combustible components of MSW by county.

	Maui		Kauai		Hawaii		Honolulu	
	Landfilled (tons)	RNG Potential* (million therms)	Landfilled (tons)	RNG Potential* (million therms)	Landfilled (tons)	RNG Potential* (million therms)	Landfilled (tons)	RNG Potential* (million therms)
Non-Food Biomass Components	111,151	7.2	43,279	3.8	120,346	13.2	22,207	2.4
Plastics and Textiles	40,823	5.5	13,904	3.0	27,616	5.8	6,440	1.4
Totals	151,974	12.7	57,183	6.8	147,963	18.9	28,647	3.8

*RNG potential based on moisture, energy content, assumed 90% material recovery & preparation yield, and 60% conversion efficiency from Tchobanaglous et al., 1993; Themelis et al., 2002; GTI, 2019; Alamia et al., 2017.
See Appendix H for SI unit version of this table

CDW is disposed separately in the City & County of Honolulu. Approximately 260,000 tons per year (~700 tons per day) (~236,000 Mg y^{-1} or 635 Mg d^{-1}) of CDW is disposed at the PVT CDW landfill in Nanakuli. Roughly 20% of the material is inert with the remainder combustible with an energy content of 7,740 Btu/lb (18 MJ kg^{-1}) (Bach et al., 2019). Assuming 90% material recovery and preparation yield and 60% conversion efficiency (Alamia et al., 2017; GTI, 2019), the CDW material landfilled on Oahu could potentially produce up to 28.5 million therms (3,000 TJ) per year of RNG.

3.2.2 Agricultural and forestry residues

A summary of the change of Hawaii's land use for agriculture and commercial forestry from 1935 to present is summarized in Figure 6. Note that acreage is presented using a logarithmic scale. The reduced footprint of the two long time mainstays of Hawaii agriculture, sugarcane and pineapple, is readily apparent. The closure of Hawaiian Commercial & Sugar in 2016 eliminated sugar cane acreage for large scale production of raw sugar. Current cultivation supports rum production on several islands and is estimated to be on the order of 1,000 acres (405 ha) in total. Current pineapple production services fresh markets and canning operations have ceased, leading to lower acreage.

Between 15,000 and 18,000 acres (6,070 – 7,280 ha) of macadamia nuts have been harvested annually over the past 20 years with average gross production of nut-in-shell of ~25,000 tons (22,675 Mg) per year. Nut shells suitable for use as feedstock for thermochemical conversion would be expected to be ~15,000 tons (13,600 Mg). Shells are commonly used as boiler fuel to provide electricity and supplemental heat for processing operations, thereby reducing their availability. Macadamia nut shells are a high quality biomass fuel, having both low moisture content and energy content of ~20 MJ/kg, however their availability as fuel for thermochemical RNG production is limited.

The forest industry in Hawaii includes four sectors:
1) eucalyptus;
2) koa;
3) sandalwood;
4) other species for local use (craft eucalyptus for flooring, kamani, milo, etc.).

While commercial forestry area across the state was estimated at ~23,000 acres (9300 ha) in 2015 (Melrose et al., 2015), actual harvesting for timber production that would be expected to generate forest residues (typically call slash, composed of limbs and smaller diameter wood) is limited (Friday, 2021).

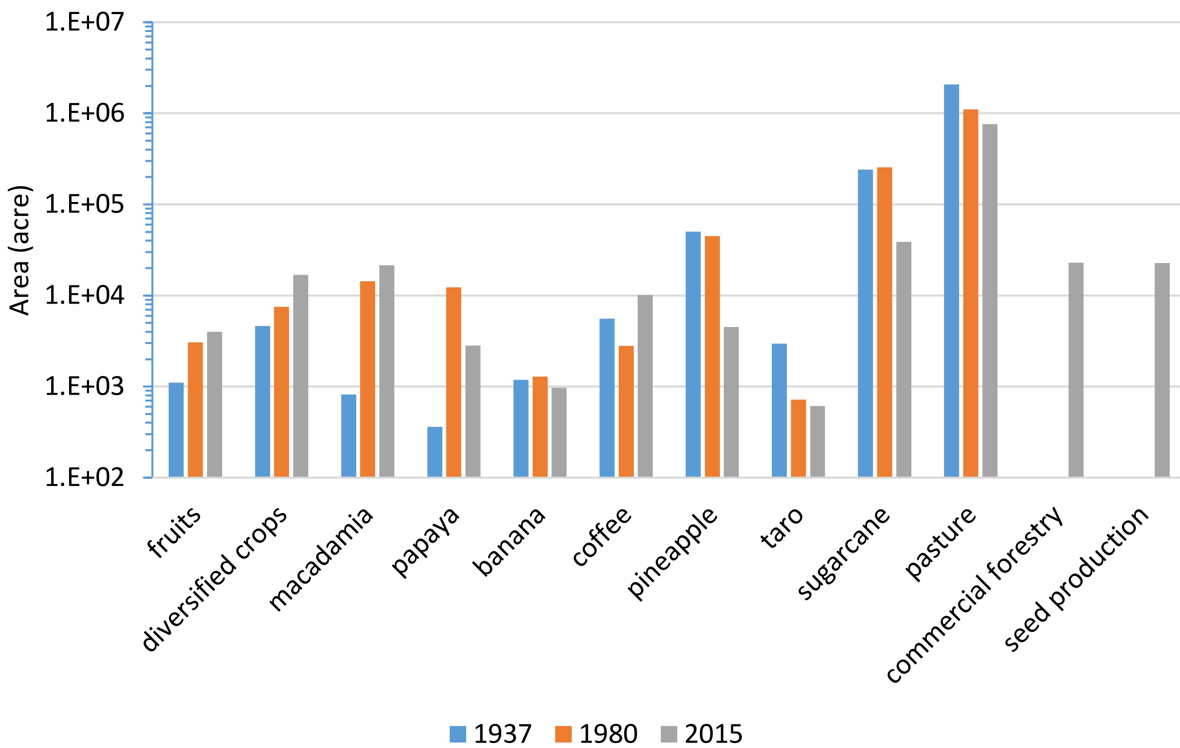

Figure 6. A summary of the change of Hawaii's land use for agriculture and commercial forestry from 1935 to 2015. (Melrose et al., 2015)

3.2.3 Purpose-grown energy crops

Purpose-grown energy crops to support production of electricity and transportation fuels in Hawaii have been explored several times over the past 40 years (Brewbaker, 1980; Troy, 1982; Fujita, Bodle, and Yuen, 1982; Hubbard et al., 1993; Kinoshita et al., 1995; Kinoshita and Zhou, 1999; Kinoshita and Turn, 2004; Kinoshita and Turn, 2005; Keffer et al., 2006; Poteet, 2006; Keffer et al., 2009; Turn et al., 2009). These studies have typically considered fast growing trees (eucalypts or leucaena) or grasses (sugar cane, fiber cane, or banagrass) with the exception of the oil crop assessment by Poteet (2006). These include both statewide assessments and those focused on a specific location (infrastructure and environment). Interest was driven by the decline of the sugar industry and the state's dependence on imported petroleum; both of these themes remain timely.

The state's ~4 million acres (1.6 million ha) are classified into land use districts and just less than half falls in the agricultural land use district. Based on geographic information system data (SOH-OOP, 2019), estimates of agricultural land in Hawaii are summarized by island in Table 11 including information on the type of land and slope. Land capability class (LCC) is one method to classify soils and provides an index (value of 1 through 8; lower values are favorable) of limitations for agricultural use. In general, LCCs in the range from 1 to 4 have increasing degrees of limitations (1 lower and 4 higher) but these limitations can be managed by the choice of plants and by adopting conservation practices. LCCs of 5 and 6 have greater limitations and are generally suitable for pasture, range or forestry (NRCS, 2019). Slope data were derived from an interferometric synthetic aperture radar data set (InterMap Technologies Inc., Englewood, CO). Roughly 640,000 acres (260,000 ha) across the state are in LCCs 1 to 4 and have a slope of less than 20%. LCCs of 5 and 6 with slope less than 20% total ~180,000 acres (72,800 ha). Slope is a consideration for erosion control and machinery operations.

Table 11. Summary of area (acres) in the agricultural land use district in the State of Hawaii.

	Agricultural Land Use District (2015 data)				
Island	Total	LCC 1-4	LCC 5-6	LCC 1-4 Slope ≤20%	LCC 5-6 Slope ≤20%
Kauai	144,348	77,709	13,996	67,142	7,302
Oahu	120,790	43,912	5,126	41,602	2,215
Molokai	110,791	42,251	13,426	40,242	8,919
Lanai	44,612	21,837	1,832	21,056	1,459
Maui	235,230	101,533	54,987	87,545	28,708
Hawaiʻi	1,183,333	469,605	167,669	386,061	134,320
Total	1,839,104	756,847	257,036	643,648	182,923
LCC – land capability class					

See Appendix H for SI unit version of this table

Agricultural land in use as of 2015 is summarized in Table 12 based on the study conducted by Melrose, et al. (2015). Pasture has the largest single footprint on the Hawaii agricultural landscape occupying more than 750,000 acres (304,000 ha) of the 1.8 million acres (728,000 ha) in the agricultural land use district. Crop land is roughly 1/6th of this amount at ~125,000 acres (50,600 ha). Figures 7 to 9 show the (a) areas of the agricultural land use district with slope less than 20% and land capability classes from 1 to 6, (b) 2015 agricultural land use (Melrose et al., 2015), and (c) their difference, representing an estimate of agricultural lands with slope less than 20% and land capability classes from 1 to 6 which is underutilized. Figure 9 indicates that ~250,000 acres (101,000 ha) of these underutilized lands lie in land capability classes 1 to 4 while ~75,000 acres (30,350 ha) are in land capability classes 5 and 6. Table 13 summarizes underutilized land resources by island. Note that recent events, such as the changes resulting from the 2016 closure and subsequent sale of Hawaiian Commercial & Sugar Co., are not reflected in these figures. Updating the agricultural land use study by Melrose et al. (2015) would be helpful. Nonetheless, this information provides a starting point for assessing agricultural land resources that could support feedstock production for thermochemical RNG systems. As noted above, Kinoshita et al. (1995) estimated that 12,000 acres (4,860 ha) of land with adequate water availability could produce ~260,000 tons (236,000 Mg) of dry fiber per year based on assumptions of 21.5 tons dry matter per acre per year (48.2 Mg ha^{-1} y^{-1}) and a harvest frequency of 8 months. Similarly, fiber production from trees (Kinoshita and Zhou, 1999; Keffer et al., 2006) at a mean annual growth increment of 10 tons per acre per year (22.4 Mg ha^{-1} y^{-1}) and a harvest frequency of four to five years would require ~26,000 acres (10,500 ha).

Comparing these production area requirements and the rudimentary assessment of underutilized land, it would appear that land resources would not limit feedstock production to either support a facility in its entirety or in part if feedstocks were combined with other fiber resources. This comparison does not address the availability of other factors of production needed for a successful agricultural enterprise or the political, social, cultural, or regulatory environments that would be equally important. All would necessarily depend on site specific details.

Table 12. Summary of Hawaii agricultural land use (acres) in 2015 (Melrose et al., 2015).

Island	Total	Crops	Commercial Forestry	Pasture
Kauai	63,244	19,567	1,743	41,934
Oahu	40,818	22,328	26	18,464
Molokai	41,854	3,593	-	38,261
Lanai	65	65	-	-
Maui	151,808	43,327	33	108,447
Hawai'i	615,473	40,088	21,061	554,324
Total	913,261	128,967	22,864	761,429

See Appendix H for SI unit version of this table

Table 13. Underutilized land resources in Hawaii by island as shown in Figure 9.

	LCC 1 to 4		LCC 5 and 6	
	(acres)	(hectares)	(acres)	(hectares)
Kauai	26,994	10,924	3,955	1,601
Oahu	18,104	7,326	1,629	659
Molokai	21,074	8,528	5,641	2,283
Lanai	20,991	8,495	1,459	590
Maui	29,498	11,937	7,115	2,879
Hawaii	135,171	54,702	57,089	23,103
Total	251,832	101,913	76,888	31,115

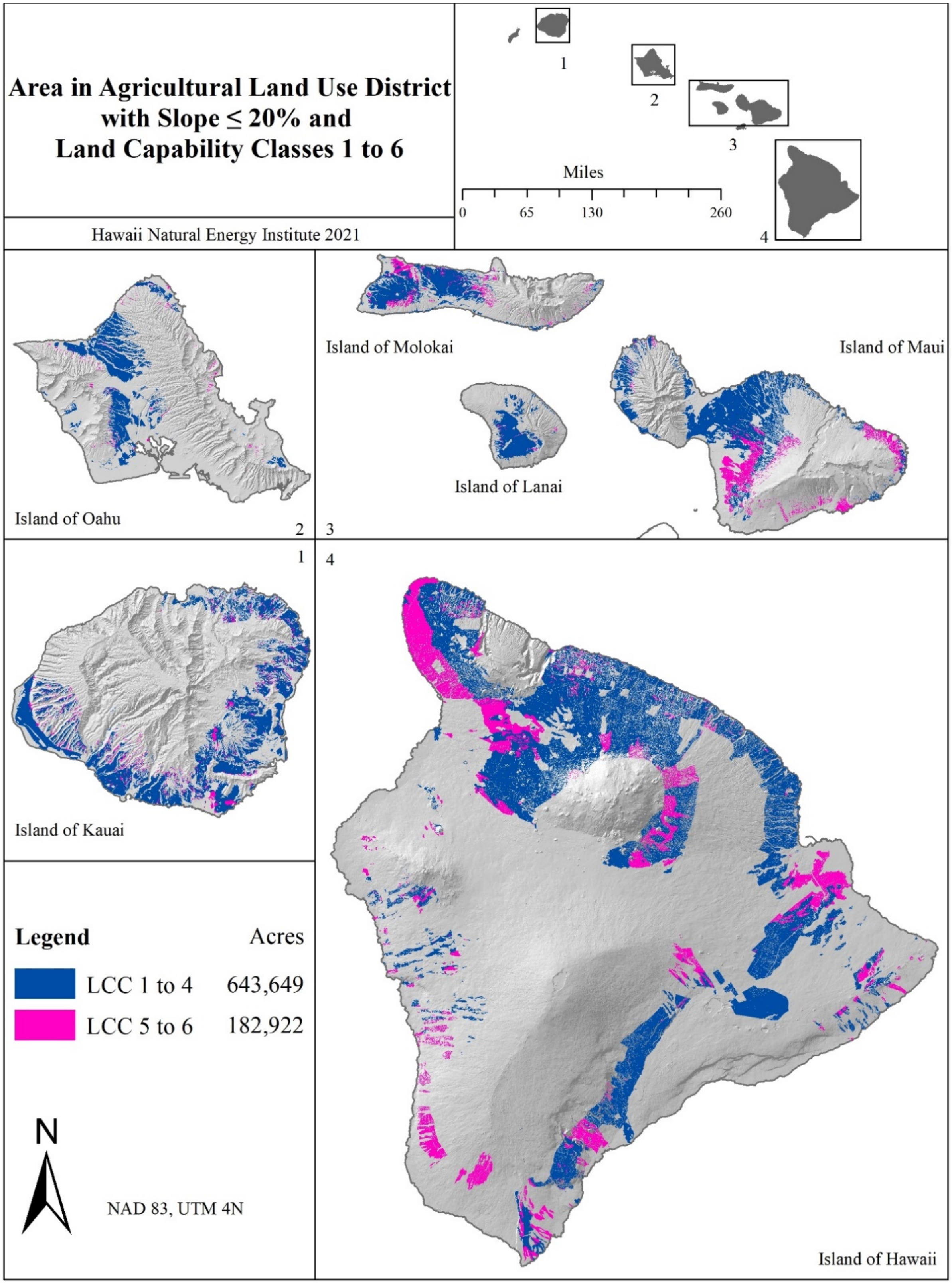

Figure 7. Area of the agricultural land use district with slope <20% and land capability classes 1 through 6. (Note 643,649 acres = 260,476 ha; 182,922 acres = 74,026 ha)

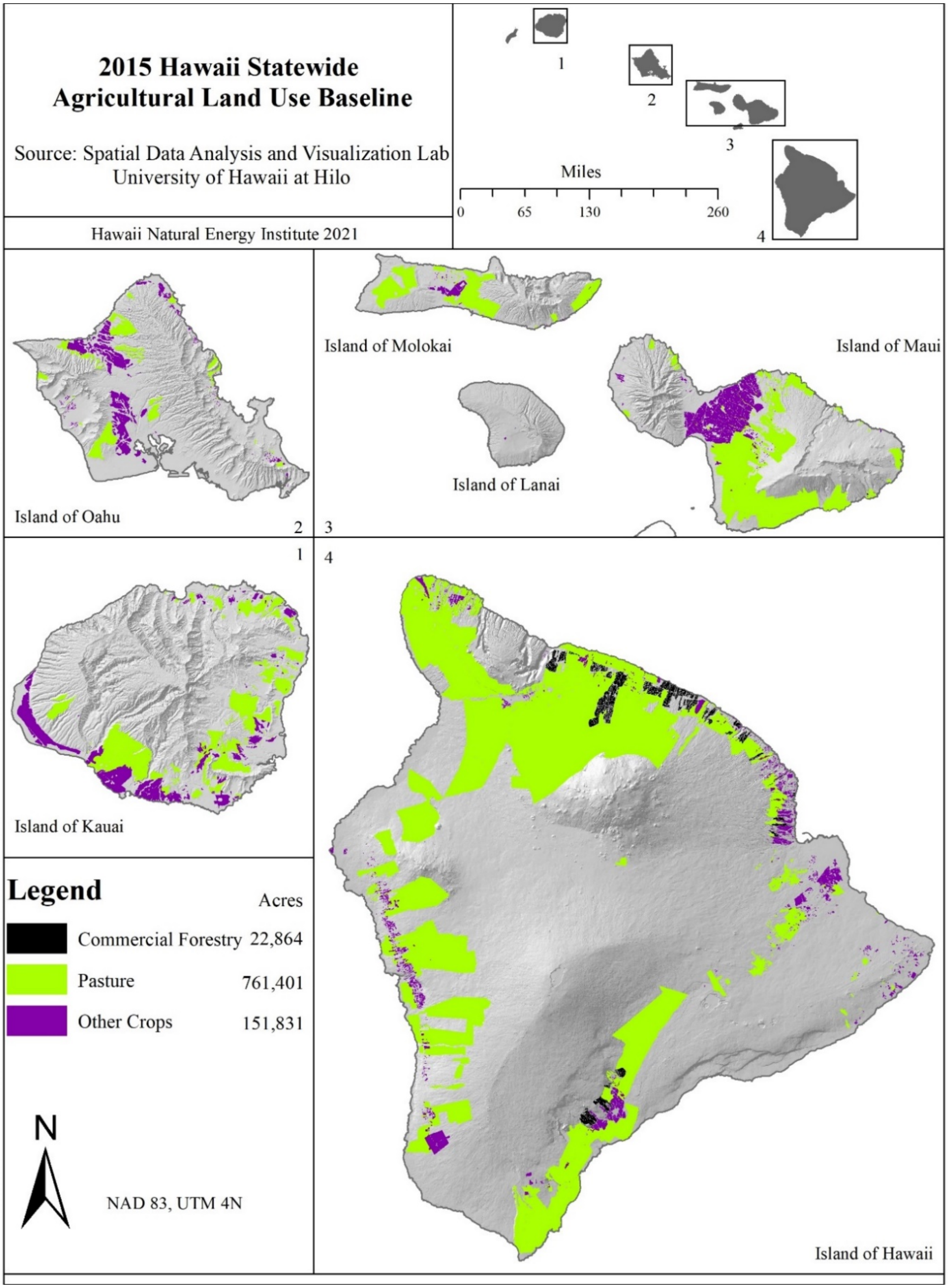

Figure 8. 2015 use of agricultural land in the State of Hawaii for commercial forestry, pasture, and crops (Melrose, 2015). (Note 22,864 acres = 9,253 ha; 761,401 acre = 308,128 ha; 151,831 = 61,444 ha)

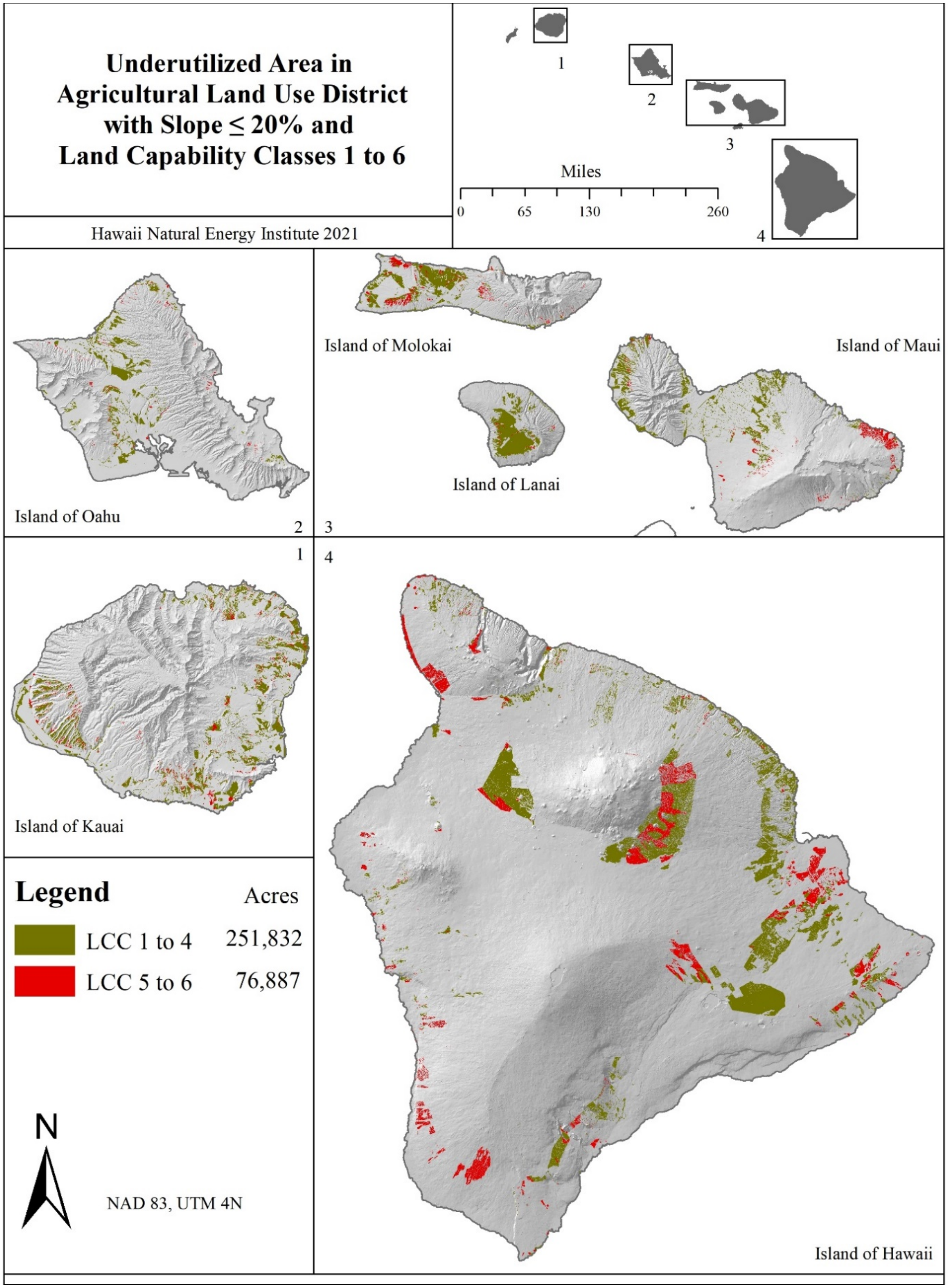

Figure 9. Underutilized area of the agricultural land use district with slope <20% and land capability classes 1 through 6. (Note, 251,832 acre = 101,913 ha; 76,887 acre = 31,115 ha)

4. Summary and Conclusions

Feedstock resources for renewable natural gas (RNG) production by biological and thermochemical conversion methods in Hawaii have been reviewed. Estimates of resources for biological production have the potential to support 13.2 million therms per year (1,390 TJ y^{-1}, note that 1 therm = 100,000 Btu) of RNG production statewide (Table ES1). Similarly, estimates of the combustible portions of construction and demolition waste and municipal solid waste have the potential to generate 70.8 million therms per year (7,470 TJ^{-1}) of RNG production statewide. Honolulu has the largest resource base for these urban waste streams. Underutilized agricultural land resources in the state could support substantial RNG production from dedicated energy crops (~1,000 to 2,000 therms per acre per year (260 – 520 GJ ha^{-1} y^{-1})), although agronomic suitability of specific candidate energy crops would need to be evaluated and confirmed.

The estimates of potential RNG feedstock resources and RNG product provided in this report do not take into consideration factors including economics, accessibility of a resource, availability of complementary factors of production, or the political, social, cultural, or regulatory environment. These factors would need to be considered in order to assess viability. Location of resources and access to infrastructure needed to implement successful RNG production, transmission, and distribution would necessarily depend on site specific details which are not included in this report.

Table 14. Summary of RNG potential (million therms RNG/year) for resources in Hawaii.

Resource Type	Maui	Kauai	Hawaii	Honolulu	State Total
Livestock Manure	*	*	*	*	*
Wastewater Treatment Plants	–	0.02	0.06	1.8	1.9
Landfill Gas	2.2	1.0	0.6	2.5	6.2
Food Waste portion of MSW	1.8	0.5	2.3	0.5	5.1
Combustible portion of MSW	12.7	6.8	18.9	3.8†	42.3
CDW	-	-	-	28.5	28.5
Agricultural and Forestry Residues	‡	‡	‡	‡	‡
Energy Crops	§	§	§	§	§
Totals⸙	>17	>8	>22	>37	>84

* Insufficient number and size of animal feeding operations to justify methane production and recovery
† Estimated amount that is currently landfilled exclusive of HPOWER use
‡ Insufficient available agricultural residues and ongoing forestry harvesting residues
§ Underutilized agricultural land resources in the State could support substantial RNG production from dedicated energy crops (~1,000 to 2,000 therms per acre per year).
⸙ Totals would be larger with implementation of energy crop based RNG production.

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Appendix A. Summary of natural gas quality standards for pipelines.

Reproduced from: https://www.socalgas.com/1443740736978/gas-quality-standards-one-sheet.pdf

Pipeline Company	Heating Value (Btu/scf)		Water Content	Various Inerts			Hydrogen Sulfide (H_2S)
	Min	Max	(Lbs/ MMscf)	CO_2	O_2	Total Inerts	(Grain/100scf)
SoCalGas	990	1150	7	3%	0.20%	4%	0.25
Dominion Transmission	967	1100	7	3%	0.20%	5%	0.25
Equitrans LP	970	–	7	3%	0.20%	4%	0.3
Florida Gas Transmission Co.	1000	1110	7	1%	0.25%	3%	0.25
Colorado Intrastate Gas Co.	968	1235	7	3%	0.001%	–	0.25
Questar Pipeline Co.	950	1150	5	2%	0.10%	3%	0.25
Gas Transmission Northwest Co.	995	–	4	2%	0.40%	–	0.25

Appendix B: CAFO Definition

https://extension.usu.edu/waterquality/files-ou/Agriculture-and-Water-Quality/AFOCAFO-information/def_cafos.pdf

Regulatory Definitions of Large CAFOs, Medium CAFO, and Small CAFOs

A **Large CAFO** confines at least the number of animals described in the table below.

A **Medium CAFO** falls within the size range in the table below and either:

- has a manmade ditch or pipe that carries manure or wastewater to surface water; **or**
- the animals come into contact with surface water that passes through the area where they're confined.

If an operation is found to be a significant contributor of pollutants, the permitting authority may designate a medium-sized facility as a CAFO.

A **Small CAFO** confines fewer than the number of animals listed in the table **and** has been designated as a CAFO by the permitting authority as a significant contributor of pollutants.

Animal Sector	Size Thresholds (number of animals)		
	Large CAFOs	**Medium CAFOs**[1]	**Small CAFOs**[2]
cattle or cow/calf pairs	1,000 or more	300 - 999	less than 300
mature dairy cattle	700 or more	200 - 699	less than 200
veal calves	1,000 or more	300 - 999	less than 300
swine (weighing over 55 pounds)	2,500 or more	750 - 2,499	less than 750
swine (weighing less than 55 pounds)	10,000 or more	3,000 - 9,999	less than 3,000
horses	500 or more	150 - 499	less than 150
sheep or lambs	10,000 or more	3,000 - 9,999	less than 3,000
turkeys	55,000 or more	16,500 - 54,999	less than 16,500
laying hens or broilers (liquid manure handling systems)	30,000 or more	9,000 - 29,999	less than 9,000
chickens other than laying hens (other than a liquid manure handling systems)	125,000 or more	37,500 - 124,999	less than 37,500
laying hens (other than a liquid manure handling systems)	82,000 or more	25,000 - 81,999	less than 25,000
ducks (other than a liquid manure handling systems)	30,000 or more	10,000 - 29,999	less than 10,000
ducks (liquid manure handling systems)	5,000 or more	1,500 - 4,999	less than 1,500

[1]Must also meet one of two "method of discharge" criteria to be defined as a CAFO or may be designated.
[2] Never a CAFO by regulatory definition, but may be designated as a CAFO on a case-by-case basis.

Appendix C: Hawaii Livestock Inventory Data

USDA. 2019. Census of Agriculture, Volume 1, Chapter 2: County Level Data: Hawaii, Table 12 Hogs and Pigs – Inventory and Sales: 2017 and 2012. United States Department of Agriculture. Washington DC. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_County_Level/Hawaii/st15_2_0012_0012.pdf

Table 12. **Hogs and Pigs - Inventory and Sales: 2017 and 2012**
[For meaning of abbreviations and symbols, see introductory text.]

Item	Hawaii	Hawaii	Honolulu	Kauai	Maui
INVENTORY					
Total hogs and pigs .... farms, 2017	226	93	28	25	80
2012	231	70	60	20	81
number, 2017	(D)	2,252	(D)	(D)	1,831
2012	11,441	931	6,265	1,480	2,765
Farms by inventory:					
1 to 24 .... farms, 2017	166	71	13	12	70
2012	153	61	30	15	47
number, 2017	813	205	56	107	445
2012	(D)	(D)	(D)	134	333
25 to 49 .... farms, 2017	16	4	3	8	1
2012	33	3	7	2	21
number, 2017	570	(D)	(D)	258	(D)
2012	1,167	140	(D)	(D)	699
50 to 99 .... farms, 2017	11	5	1	4	1
2012	15	4	6	2	3
number, 2017	688	290	(D)	(D)	(D)
2012	(D)	(D)	466	(D)	(D)
100 to 199 .... farms, 2017	25	12	6	-	7
2012	15	2	4	-	9
number, 2017	2,958	1,290	740	-	928
2012	1,925	(D)	(D)	-	1,209
200 to 499 .... farms, 2017	6	1	4	-	1
2012	11	-	10	-	1
number, 2017	2,039	(D)	(D)	-	(D)
2012	3,140	-	(D)	-	(D)
500 to 999 .... farms, 2017	1	-	1	-	-
2012	3	-	3	-	-
number, 2017	(D)	-	(D)	-	-
2012	1,947	-	1,947	-	-
1,000 or more .... farms, 2017	1	-	-	1	-
2012	1	-	-	1	-
number, 2017	(D)	-	-	(D)	-
2012	(D)	-	-	(D)	-
SALES					
Hogs and pigs sold .... farms, 2017	155	50	21	22	62
2012	131	30	43	7	51
number, 2017	(D)	2,184	3,186	(D)	(D)
2012	12,529	1,508	(D)	(D)	2,403
$1,000, 2017	(D)	(D)	565	811	506
2012	(D)	127	1,084	(D)	(D)
2017 farms by number sold:					
1 to 24 .... farms	86	32	3	9	42
number	585	250	26	87	222
25 to 49 .... farms	24	4	5	5	10
number	822	136	192	158	336
50 to 99 .... farms	18	8	1	7	2
number	1,344	(D)	(D)	560	(D)
100 to 199 .... farms	10	1	4	-	5
number	1,310	(D)	(D)	-	610
200 to 499 .... farms	15	5	8	-	2
number	3,955	1,163	(D)	-	(D)
500 to 999 .... farms	1	-	-	-	1
number	(D)	-	-	-	(D)
1,000 or more .... farms	1	-	-	1	-
number	(D)	-	-	(D)	-

USDA. 2019. Census of Agriculture, Volume 1, Chapter 2: County Level Data: Hawaii, Table 11 Cattle and Calves – Inventory and Sales: 2017 and 2012. United States Department of Agriculture. Washington DC. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_County_Level/Hawaii/st15_2_0011_0011.pdf

Table 11. Cattle and Calves - Inventory and Sales: 2017 and 2012

[For meaning of abbreviations and symbols, see introductory text.]

Item		Hawaii	Hawaii	Honolulu	Kauai	Maui
INVENTORY						
Cattle and calves	farms, 2017	1,218	847	46	132	193
	2012	1,314	917	60	133	204
	number, 2017	137,930	98,851	4,984	15,004	19,091
	2012	133,957	98,059	4,708	14,777	16,413
Farms by inventory:						
1 to 9	farms, 2017	599	443	22	44	90
	2012	652	467	24	51	110
	number, 2017	2,475	1,854	61	211	349
	2012	2,706	1,931	76	245	454
10 to 19	farms, 2017	163	101	1	16	45
	2012	236	176	11	15	34
	number, 2017	2,219	1,383	(D)	(D)	603
	2012	3,065	2,269	(D)	(D)	426
20 to 49	farms, 2017	165	111	4	26	24
	2012	175	110	8	30	27
	number, 2017	4,782	3,163	116	795	708
	2012	5,057	3,161	306	870	720
50 to 99	farms, 2017	82	51	2	20	9
	2012	97	64	5	13	15
	number, 2017	5,939	3,752	(D)	(D)	688
	2012	6,745	4,516	365	892	972
100 to 199	farms, 2017	89	61	11	9	8
	2012	57	34	8	9	6
	number, 2017	12,025	8,424	1,293	1,258	1,050
	2012	7,542	4,632	1,142	1,089	679
200 to 499	farms, 2017	68	46	5	10	7
	2012	41	29	3	5	4
	number, 2017	21,014	14,402	1,851	2,932	1,829
	2012	12,546	8,761	1,157	1,650	978
500 or more	farms, 2017	52	34	1	7	10
	2012	56	37	1	10	8
	number, 2017	89,476	65,873	(D)	(D)	13,864
	2012	96,296	72,789	(D)	(D)	12,184
Cows and heifers that calved	farms, 2017	1,055	724	44	123	164
	2012	1,181	832	50	121	178
	number, 2017	80,538	59,210	3,174	7,624	10,530
	2012	73,875	55,553	2,479	7,546	8,297
Beef cows	farms, 2017	1,047	720	44	121	162
	2012	1,173	829	45	121	178
	number, 2017	(D)	(D)	3,174	7,607	10,518
	2012	(D)	(D)	2,464	7,546	8,297
2017 farms by inventory:						
1 to 9	farms	548	399	21	41	87
	number	(D)	1,535	(D)	(D)	299
10 to 19	farms	157	96	4	24	33
	number	1,972	1,185	(D)	(D)	417
20 to 49	farms	113	65	2	32	14
	number	3,404	(D)	(D)	1,079	398
50 to 99	farms	103	77	10	6	10
	number	7,427	5,549	808	452	618
100 to 199	farms	50	33	2	9	6
	number	6,642	(D)	(D)	1,255	832
200 to 499	farms	46	30	4	6	6
	number	15,051	9,500	1,194	2,255	2,102
500 or more	farms	30	20	1	3	6
	number	41,965	33,251	(D)	(D)	5,852
Milk cows	farms, 2017	20	9	-	5	6
	2012	12	7	5	-	-
	number, 2017	(D)	(D)	-	17	12
	2012	(D)	(D)	15	-	-
2017 farms by inventory:						
1 to 9	farms	18	7	-	5	6
	number	47	18	-	17	12
10 to 19	farms	-	-	-	-	-
	number	-	-	-	-	-
20 to 49	farms	-	-	-	-	-
	number	-	-	-	-	-
50 to 99	farms	-	-	-	-	-
	number	-	-	-	-	-
100 to 199	farms	-	-	-	-	-
	number	-	-	-	-	-
200 to 499	farms	-	-	-	-	-
	number	-	-	-	-	-
500 or more	farms	2	2	-	-	-
	number	(D)	(D)	-	-	-
Other cattle (see text)	farms, 2017	850	572	29	107	142
	2012	903	610	48	100	145
	number, 2017	57,392	39,641	1,810	7,380	8,561
	2012	60,082	42,506	2,229	7,231	8,116
2017 farms by inventory:						
1 to 9	farms	430	296	9	39	86
	number	1,658	1,217	(D)	(D)	256
10 to 19	farms	104	66	-	24	14
	number	1,450	926	-	308	216
20 to 49	farms	151	96	12	21	22
	number	4,573	2,779	365	734	695
50 to 99	farms	59	44	4	6	5
	number	4,087	3,113	240	362	372
100 to 199	farms	53	34	3	11	5
	number	7,393	4,970	422	1,412	589
200 to 499	farms	31	23	-	3	5
	number	9,883	7,200	-	1,195	1,488
500 or more	farms	22	13	1	3	5
	number	28,348	19,436	(D)	(D)	4,945

–continued

USDA. 2019. Census of Agriculture, Volume 1, Chapter 2: County Level Data: Hawaii, Table 19 Poultry – Inventory and Sales: 2017 and 2012. United States Department of Agriculture. Washington DC.

https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_County_Level/Hawaii/st15_2_0019_0019.pdf

Table 19. **Poultry - Inventory and Number Sold: 2017 and 2012**

[For meaning of abbreviations and symbols, see introductory text.]

Item	Hawaii	Hawaii	Honolulu	Kauai	Maui
INVENTORY					
Any poultry ....farms, 2017	766	410	97	48	211
2012	608	363	68	58	119
Layers (see text) ....farms, 2017	674	362	71	45	196
2012	523	312	49	57	105
number, 2017	192,185	7,999	(D)	1,059	(D)
2012	244,343	(D)	(D)	1,623	(D)
2017 farms by inventory:					
1 to 49	595	326	58	39	172
50 to 99	41	14	7	5	15
100 to 399	29	22	3	1	3
400 to 3,199	6	-	-	-	6
3,200 to 9,999	1	-	1	-	-
10,000 to 19,999	1	-	1	-	-
20,000 to 49,999	-	-	-	-	-
50,000 to 99,999	-	-	-	-	-
100,000 or more	1	-	1	-	-
Pullets for laying flock replacement ....farms, 2017	58	29	7	4	18
2012	79	41	19	13	6
number, 2017	23,538	(D)	(D)	166	1,126
2012	49,250	(D)	(D)	(D)	(D)
Broilers and other meat-type chickens ....farms, 2017	81	40	15	-	26
2012	93	65	14	4	10
number, 2017	12,753	(D)	(D)	-	1,437
2012	3,375	2,659	424	120	172
Turkeys ....farms, 2017	12	1	6	-	5
2012	9	1	-	1	7
number, 2017	207	(D)	102	-	(D)
2012	117	(D)	-	(D)	(D)
Ducks, geese, and other miscellaneous poultry ....farms, 2017	229	111	47	13	58
2012	156	90	31	3	32
NUMBER SOLD					
Any poultry sold ....farms, 2017	425	181	61	37	146
2012	342	186	42	47	67
Layers sold (see text) ....farms, 2017	75	27	10	6	32
2012	81	38	9	14	20
number, 2017	46,362	525	44,591	156	1,090
2012	87,836	1,829	74,330	805	10,872
Pullets for laying flock replacement sold ....farms, 2017	10	-	4	3	3
2012	12	4	6	-	2
number, 2017	(D)	-	(D)	36	300
2012	(D)	727	(D)	-	(D)
Broilers and other meat-type chickens sold ....farms, 2017	31	8	6	-	17
2012	22	11	7	2	2
number, 2017	8,356	98	(D)	-	(D)
2012	2,639	1,120	1,471	(D)	(D)
2017 farms by number sold:					
1 to 1,999	30	8	5	-	17
2,000 to 59,999	1	-	1	-	-
60,000 to 99,999	-	-	-	-	-
100,000 to 199,999	-	-	-	-	-
200,000 to 499,999	-	-	-	-	-
500,000 or more	-	-	-	-	-
Turkeys sold (see text) ....farms, 2017	5	1	-	-	4
2012	-	-	-	-	-
number, 2017	89	(D)	-	-	(D)
2012	-	-	-	-	-
Ducks, geese, and other miscellaneous poultry sold ....farms, 2017	79	24	27	10	18
2012	62	27	16	2	17

Appendix D: Hawaii landfill data from EPA greenhouse gas reporting program.

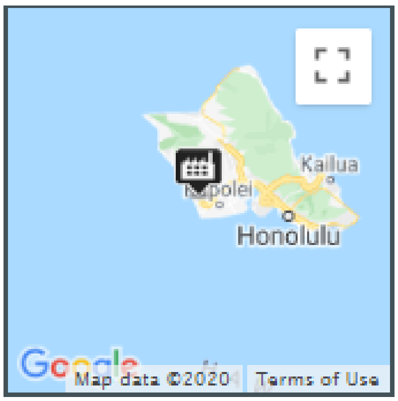
Waimanalo Gulch Landfill & Ash Monofill
https://ghgdata.epa.gov/ghgp/service/facilityDetail/2018?id=1007708&ds=E&et=&popup=true

Data Year 2018 ▼

Facility Information | Facility Emissions by Year

CITY & COUNTY OF HONOLULU – WAIMANALO GULCH MSWLF

92-460 FARRINGTON HIGHWAY
KAPOLEI, HI, 96707

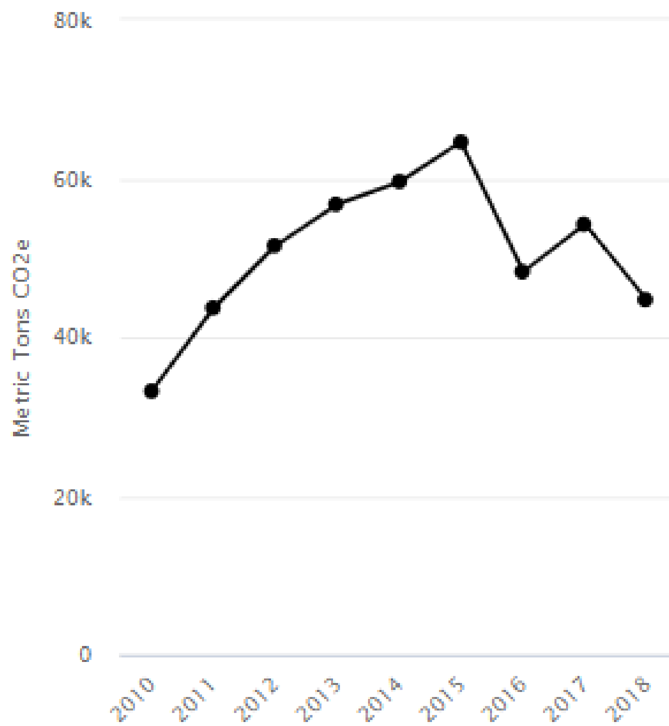


Latitude: 21° 20.65' N
Longitude: 158° 07.06' W

GHGRP Id: 1007708
FRS Id: 110014055501
NAICS Code: 562212

View reported data

Download reported data (XML)



Kekaha Landfill Phases I & II

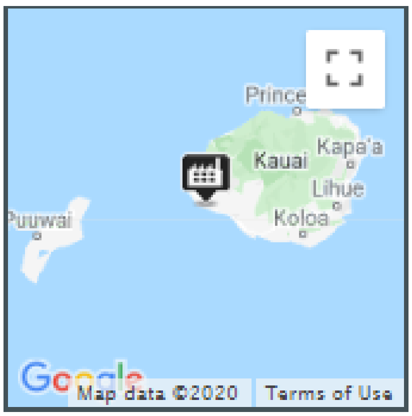
https://ghgdata.epa.gov/ghgp/service/facilityDetail/2018?id=1000216&ds=E&et=&popup=true

Data Year 2018 ▼

Facility Information | Facility Emissions by Year

Kekaha Landfill

6900D Kaumualii Highway
Kekaha, HI, 96752

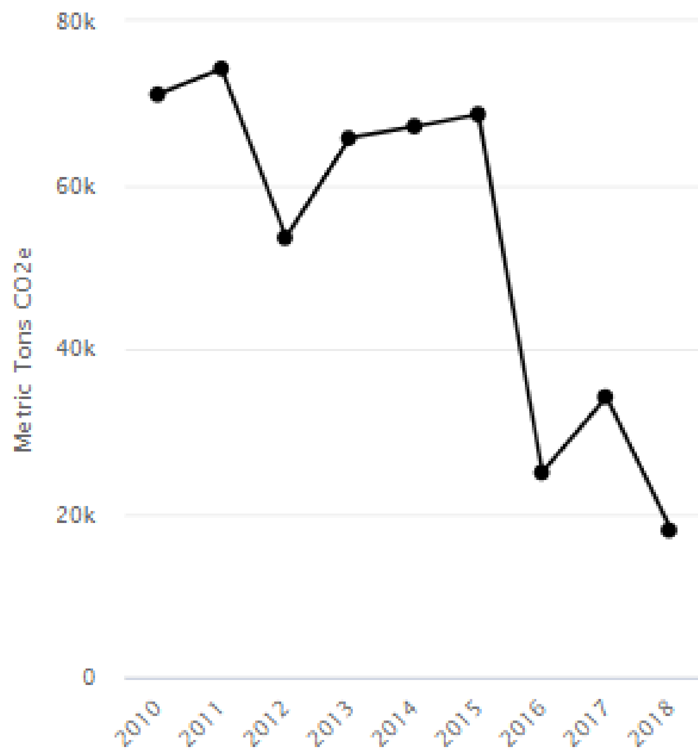


Latitude: 21° 58.53' N
Longitude: 159° 44.27' W

GHGRP Id: 1000216
FRS Id: 110043801151
NAICS Code: 562212

View reported data

Download reported data (XML)



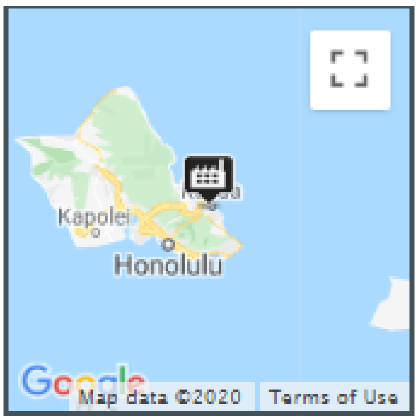
Kapaa and Kalaheo Sanitary Landfills
https://ghgdata.epa.gov/ghgp/service/facilityDetail/2018?id=1001595&ds=E&et=&popup=true

Data Year 2018 ▼

Facility Information | Facility Emissions by Year

Kapaa and Kalaheo Sanitary Landfills

913 Kalanianaole Hwy
Kailua, HI, 96734

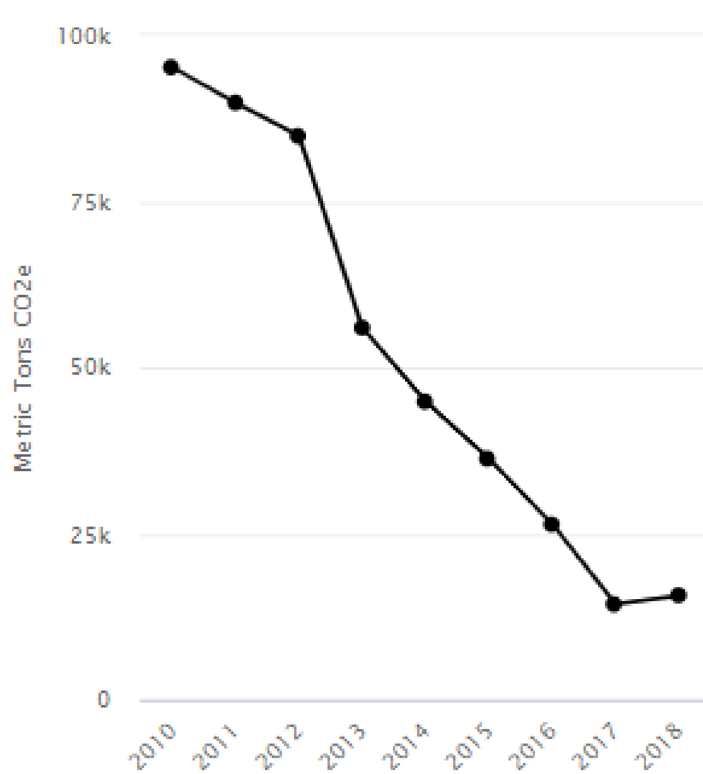


Latitude: 21° 23.58' N
Longitude: 157° 44.98' W

GHGRP Id: 1001595
FRS Id: 110043685991
NAICS Code: 562212

View reported data

Download reported data (XML)



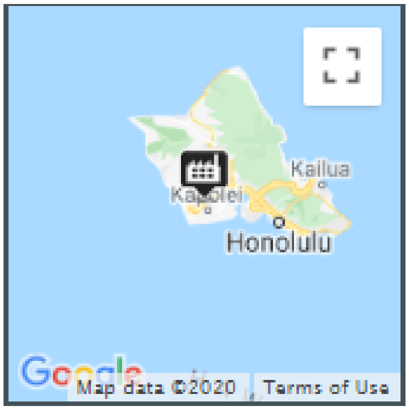
Palailai Landfill
https://ghgdata.epa.gov/ghgp/service/facilityDetail/2018?id=1004803&ds=E&et=&popup=true

Data Year 2018 ▼

Facility Information | Facility Emissions by Year

Palailai Landfill

91-402 Farrington Highway
Kapolei, HI, 96707

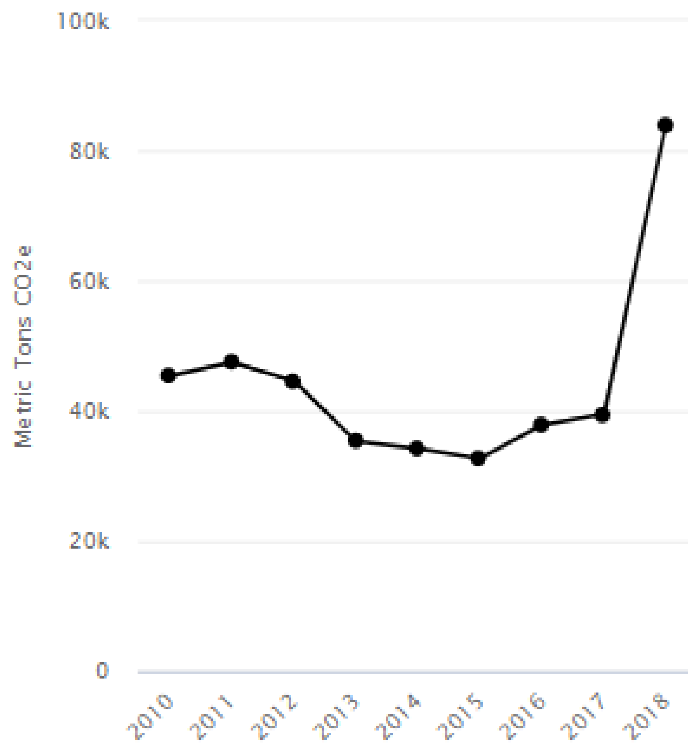


Latitude: 21° 20.95' N
Longitude: 158° 03.90' W

GHGRP Id: 1004803
FRS Id: 110043812078
NAICS Code: 562212

View reported data

Download reported data (XML)



Central Maui Landfill Refuse and Recycling Center
https://ghgdata.epa.gov/ghgp/service/facilityDetail/2018?id=1005313&ds=E&et=&popup=true

Facility Information | Facility Emissions by Year

Data Year 2018

CENTRAL MAUI LANDFILL REFUSE & RECYCLING CENTER

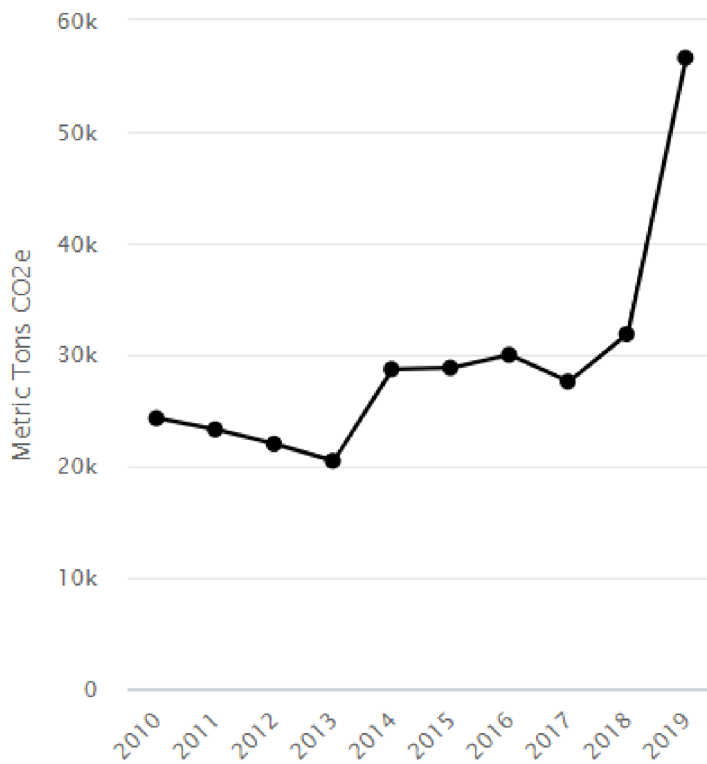
1 PULEHU ROAD
PUUNENE, HI, 96784

Latitude: 20° 51.60' N
Longitude: 156° 25.14' W

GHGRP Id: 1005313
FRS Id: 110043806012
NAICS Code: 562212

View reported data

Download reported data (XML)



West Hawaii Landfill/Pu`uanahulu

https://ghgdata.epa.gov/ghgp/service/facilityDetail/2018?id=1006173&ds=E&et=&popup=true

Data Year 2018 ▼

Facility Information | Facility Emissions by Year

WEST HAWAII LANDFILL / PUU ANAHULU

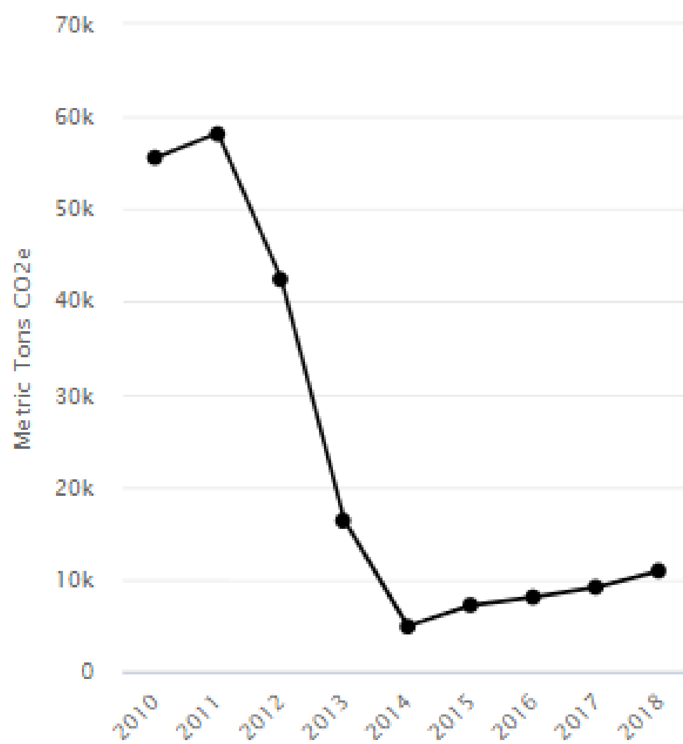
71-111 QUEEN KAAHUMANU HWY
WAIKOLOA, HI, 96738

Latitude: 19° 54.29' N
Longitude: 155° 52.99' W

GHGRP Id: 1006173
FRS Id: 110034132542
NAICS Code: 562212

View reported data

Download reported data (XML)



Appendix E: City & County of Honolulu Ordinance Chapter 9, Section 9-3.5 Food Waste Recycling

Sec. 9-3.5 Food waste recycling.

(a) The owners of the following food establishments located within the City and County of Honolulu shall: (i) arrange and provide for the separate collection of food waste and for its recycling by a recycling facility in the city; or (ii) separate food waste from all other solid waste generated by the food establishment and deliver the food waste to a recycling facility:

(1) A restaurant that occupies 5,000 square feet or more of floor area and serves 400 or more prepared meals per day based on an annualized average. If a restaurant is also a catering establishment, it shall be considered a restaurant for purposes of this section. If a restaurant has on its premises a place where the primary method of service, for all mealtimes, is food and drink orders taken and served to customers at a self-service counter, that portion of the premises devoted to the taking and serving of such food and drink orders, and any dining area serving customers of such self-service counter, shall not be counted in determining the square feet of the restaurant or the number of prepared meals served by the restaurant.

(2) A food court as defined in subsection (g). The company or entity that manages the shopping center or building where the food court is located shall be required to comply with the requirements of this section unless the owners of the food establishments in the food court are responsible for the disposal of their refuse, in which case the owners of those establishments shall be responsible for complying with this section.

(3) A hotel with a kitchen or kitchens and one or more function rooms. For the purposes of this subdivision,

(Continued on following pages)

a "kitchen" means that place which is not part of a restaurant and where food is prepared for hotel employees or functions on the hotel's premises.

(4) A market that occupies 18,000 square feet or more of floor area.

(5) A food manufacturer or processor that occupies 5,000 square feet or more of floor area.

(6) A catering establishment that is not also a restaurant or part of a restaurant and which serves or sells 400 or more prepared meals per day based on an annualized average.

(7) A hospital which serves 400 or more prepared patient meals a day based on an annualized average.

For the purposes of this subsection, for the first year following January 1, 1997,* the annualized average number of prepared meals served or sold per day by a food establishment shall be the average number of meals prepared per day in the year prior to January 1, 1997,* for food establishments that have been in existence for one year or more prior to January 1, 1997.* For establishments that have not been in existence for that length of time prior to January 1, 1997,* the annualized average shall be determined based on the number of prepared meals served or sold per day during the first year that the food establishment has been in existence following January 1, 1997.* Except as provided above, establishments shall use the prior year=s average number of prepared meals served or sold per day in determining whether they are required to recycle their food waste in accordance with this section.

(b) This section shall not apply to any church or nonprofit organization except a hospital, as provided in subsection (a). Further, this section shall not apply to any food service establishment which offers as the primary method of service, for all mealtimes, food and drink orders taken at and served to the customer at a self-service counter; provided that this exemption shall not apply to food establishments in markets or establishments in a food court.

(c) The requirement to recycle food waste under this section shall be applicable only to the food waste from kitchens and food preparation, handling, and manufacturing or processing areas, and from dining areas where customers are served by waiters or waitresses, or where tables or meals are cleared away by employees of the business or establishment.

The requirement of this subsection shall not apply to commercial cooking oil waste or commercial FOG waste. Instead, the removal, transport, and disposal of such waste shall be subject to Chapter 14, Article 5A.

(d) A food establishment that is required to recycle food waste under this section may combine such waste with that of other establishments, or may separately collect and recycle its own food waste.

(e) All food establishments otherwise required to recycle food waste under this section shall not be required to do so if the disposal charge for disposing of food waste at a recycling facility in the city, including the cost of transporting the food waste to the facility, exceeds the tipping fee or disposal charge for disposing of waste at the HPOWER facility, as provided in Section 9-4.2, plus the cost of transporting refuse to such facility. The chief shall make this determination.

(f) The owner of a food establishment that is otherwise required to recycle food waste may petition the chief to suspend the applicability of this section to the applicant if the applicant demonstrates that recycling service for food waste is unavailable to the applicant. If the chief grants the application, the requirements of this section shall be suspended until such time as recycling service becomes available to the applicant. The chief shall, from time to time, review the availability of recycling service to food establishments for which the requirements of this section have been suspended. If the chief determines that recycling service is available and that the requirements of this section shall no longer be suspended with regard to a particular food establishment, the chief shall notify the owner of the establishment by registered mail and that owner shall be required to recycle food waste in accordance with this section within sixty days of receipt of the notice.

The chief may also, on the chief's own initiative, suspend the requirements of this section:

(1) During the period of a work stoppage or any other interruption of recycling collection service to the food establishments that are subject to this section; or

(2) Whenever the chief determines that there are inadequate recycling facilities or there is inadequate recycling capacity to dispose of the food waste being collected pursuant to this section.

(g) For the purposes of this section:

"Catering establishment" means the same as defined in Section 21-10.1.

"Composting facility" means an establishment that conducts either major or minor composting operations, as defined in Section 21-10.1.

"Food bank" means a facility that receives donations of food for redistribution to needy groups, individuals or families.

"Food court" means an area within a building or shopping center where five or more food establishments are situated and serviced by a common dining area.

***Editor's Note:** "January 1, 1997" is substituted for "the effective date of this ordinance".

"Food establishment" means a catering establishment, food court, food manufacturer or processor, hospital, hotel, market, or restaurant.

"Food manufacturer or processor" includes an establishment that generates food waste and is primarily involved in the manufacture or processing of food products, including animal products, but excluding baked goods.

"Food waste" means the same as that term is defined under the definition of Arecyclable materials" in Section 9-1.2.

"Function room" means an area within a hotel where events are held at which food is served, including but not limited to wedding receptions, business meetings, conferences, banquets and parties.

"Hospital" means the same as defined in Section 21-10.1.

"Hotel" means the same as defined in Section 21-10.1.

"Market" includes establishments where fresh meat, fish or produce is prepared, handled and displayed for sale at retail or wholesale.

"Meal" includes any food item or items served as an entree at breakfast, lunch or dinner, but excludes beverages and desserts, if the beverages or desserts are served by themselves and not part of a breakfast, lunch or dinner.

"Prepared meals" means meals that have been cleaned, cooked, or otherwise prepared on the premises of the food establishment, and shall exclude prepackaged meals that are cooked or otherwise prepared elsewhere and only sold on the premises of the establishment. APrepared meals" includes meals a portion of which have been precooked or prepared off the premises of the establishment.

"Recycling facility" includes a composting facility, waste bioconversion facility, rendering facility, pig farm or other agricultural facility that uses food waste as animal feed or for other agricultural use, or any other facility that recycles food waste and is approved by the director for that purpose.

"Recycling service" is a service or collection of services that includes the collection and transportation of food waste to a recycling facility by a refuse hauler or other company that collects the food waste, and the recycling or reuse of that food waste by a recycling facility, which may or may not be operated by the company that collects and transports the food waste.

"Rendering facility" means an establishment that converts kitchen grease, cooking oils, meat scraps or other slaughterhouse waste, waste from meat processing plants, or any combination of the foregoing items, for use in the manufacture of such products as cosmetics, detergents, plastics, paints, tires and animal feed products.

"Restaurant" means a place of business where food is served for compensation and includes the kitchen or food preparation area of that place of business, but excludes any portion of the establishment that is a bakery serving baked goods for consumption on or off the premises of the restaurant and excludes a quick-serve food service establishment which offers as the primary method of service, for all mealtimes, food and drink orders taken at and served to the customer at a self-service counter.

"Waste bioconversion facility" means a facility where food and other organic waste are converted into useable byproducts.

(h) The department may adopt rules in accordance with HRS Chapter 91, having the force and effect of law, for the implementation, administration and enforcement of this section.

(i) Upon presentation of proper credentials, the director or the director's duly authorized representative, may enter at reasonable times any building or premises of a food establishment and inspect the books and records of a food establishment to determine compliance with the requirements of this section; provided that such entry and inspection shall be made in such a manner as to cause the least possible inconvenience to the persons in possession of the property and the owners of the food establishment; and provided further that an order of a court authorizing such entry and inspection shall be obtained prior to entry or inspection in the event that such entry or inspection is denied or resisted by the persons in possession or owners of the food establishment.

(j) On January 1, 1997* and quarterly thereafter: (1) each waste bioconversion facility in the city shall report to the refuse division on: (a) how much private refuse haulers or other companies are being charged as of the end of the quarter being reported, per unit of weight or volume, for disposing of food waste at the bioconversion facility, and how much the facility is charging per unit of weight or volume, if the facility both collected and disposed of food waste from a food establishment; (b) the amount of food waste, per unit of weight or volume, that the facility recycled during the previous quarter; and (2) each refuse hauler or other company that collects and transports food waste shall report to the refuse division on how much, per unit of weight or volume, the hauler or company charged food establishments as of the end of the quarter being reported to collect and dispose of their food waste.

(k) Nothing in this section shall preclude a food establishment from donating leftover or unsold food that is safe to consume to a food bank.

(Added by Ord. 96-20; Am. Ord. 99-32, 02-14)

Appendix F: Solid Waste Characterization Data:

City & County of Honolulu Waste Composition (Cascadia, 2018).

RESULTS

2017 Oahu Waste Composition Study

Table 5 presents detailed composition results for overall waste by material category.

Table 5. Detailed Waste Composition Results: Overall

Material	Estimated Percent	+/-	Estimated Tons	Material	Estimated Percent	+/-	Estimated Tons
Paper	**22.7%**		**180,645**	**Glass**	**1.5%**		**12,147**
Uncoated Corrugated Cardboard	6.5%	1.5%	51,967	HI-5 Glass Containers	0.5%	0.1%	3,756
Newspaper	1.5%	0.8%	12,070	Non-HI-5 Glass Containers	0.6%	0.2%	4,814
Paper Bags	0.6%	0.1%	5,131	Other Glass	0.5%	0.2%	3,578
White and Colored Ledger Paper	0.9%	0.3%	7,056				
Mixed Recyclable Paper	5.5%	1.1%	43,298	**Inerts and C&D Materials**	**14.7%**		**116,691**
Compostable Paper	5.7%	0.8%	45,660	Untreated Wood	1.6%	1.3%	12,634
Other Paper	1.9%	0.9%	15,462	Treated Wood	3.4%	1.1%	27,042
				Pallets	5.9%	3.1%	46,722
Plastic	**9.8%**		**78,137**	Gypsum Wallboard	0.7%	0.8%	5,325
HI-5 Plastic PET Containers	0.4%	0.1%	2,795	Asphalt Roofing	0.0%	0.0%	117
Non-HI-5 Plastic PET Containers	0.3%	0.0%	2,551	Asphalt Paving	0.0%	0.0%	0
HI-5 Plastic HDPE Containers	0.0%	0.0%	201	Concrete	0.1%	0.0%	749
Non-HI-5 Plastic HDPE Containers	0.6%	0.1%	4,391	Ceramics	0.4%	0.4%	3,483
Other Bottles/Containers	1.0%	0.2%	7,912	Sand/Soil/Rock/Dirt	0.1%	0.1%	887
Mixed Rigid/Durable Plastics	1.8%	0.4%	14,146	Other C&D Material	2.5%	1.2%	19,731
Plastic Bags	0.1%	0.0%	838				
Other Plastic Film/Wrap	4.4%	0.6%	35,339	**Household Hazardous Waste**	**0.6%**		**4,822**
Expanded Polystyrene	0.8%	0.2%	6,268	Pesticides/Herbicides	0.0%	0.0%	25
Other Plastic	0.5%	0.1%	3,698	Paints/Adhesives/Solvents	0.0%	0.0%	370
				Household Cleaners	0.0%	0.0%	145
Metal	**4.6%**		**36,662**	Other Automotive Products	0.1%	0.1%	526
HI-5 Aluminum Containers	0.2%	0.0%	1,372	Batteries	0.0%	0.0%	389
Non-HI-5 Aluminum Containers and Scrap	0.3%	0.1%	2,345	Other HHW	0.4%		3,366
HI-5 Bi-metal Containers	0.0%	0.0%	236				
Tin/Steel Containers	0.5%	0.1%	4,065	**Other Materials**	**10.4%**		**82,930**
Other Ferrous Metals	2.5%	1.1%	19,726	Sewage Sludge	2.5%		19,733
Other Non-Ferrous Metals	0.3%	0.2%	2,167	Sewage Screenings/Grit	0.2%		1,368
Other Metals	0.8%	0.2%	6,750	Industrial Sludges	0.2%		1,753
				Tires	0.1%	0.1%	828
Organics	**35.5%**		**282,334**	Furniture	1.2%	0.3%	9,652
Food Waste-Vegetative	8.3%	1.3%	65,980	Appliances	0.3%	0.3%	2,455
Food Waste-Non-Vegetative	11.8%		93,853	Covered Electronic Devices	1.1%	0.8%	8,723
Green Waste	6.0%	1.1%	47,880	Non-Covered Electronic Devices	0.1%	0.1%	1,064
Stumps	0.2%	0.1%	1,402	Auto Fluff	2.7%		21,756
Textiles	2.9%	0.5%	23,238	Mixed Residues	2.0%		15,598
Carpet	0.5%	0.4%	4,107				
Other Organics	5.8%		45,875	**Totals**	**100.0%**		**794,368**
				Sample Count			**312**

Confidence intervals calculated at the 90% confidence level. Percentages for material types may not total 100% due to rounding.

For this substream, error rates (+/-) for certain materials cannot be calculated because additional weight data from scalehouse records was added to those special waste material types. Estimated percents and error rates that are provided in this table have been revised to adjust for the addition of scalehouse weight data.

County of Maui Waste Composition from RWBeck (2009) [The Maui 2008 ISWMP by GBB (2008) used the 2006 Kauai waste characterization, which appears in RWBeck. (2009)]

Table 2-8
Solid Waste Stream Composition

Material Group	Material	Percent Residential Waste Stream	Percent of Commercial Waste Stream
Paper	Newsprint	5.9%	5.3%
	Magazines	3.0%	2.8%
	High Grade Office Paper	0.8%	2.3%
	OCC and Kraft Bags	5.0%	11.3%
	Mixed Recyclable Paper	7.9%	5.3%
	Non-Recyclable Paper	3.5%	3.3%
	Compostable Paper	7.8%	8.2%
Total Paper		**33.8%**	**38.5%**
Plastics	#1 PET Beverage Containers	0.6%	0.3%
Plastics	#1 PET Deposit Beverage Containers	0.4%	0.5%
Plastics	#2 HDPE Containers	1.5%	1.3%
Plastics	#2 HDPE Deposit Containers	0.0%	0.0%
Plastics	#6 Polystyrene	1.2%	2.3%
Plastics	Other Plastic Containers	0.4%	0.4%
Plastics	Other Plastic Products	3.2%	3.9%
Plastics	Film/Wrap/Bags	6.0%	6.3%
Total Plastics		**13.4%**	**15.0%**

County of Maui Waste Composition (continued).

Material Group	Material	Percent Residential Waste Stream	Percent of Commercial Waste Stream
Metals	Aluminum Non-Deposit Beverage Containers	0.0%	0.0%
Metals	Aluminum Deposit Beverage Containers	0.4%	0.4%
Metals	Ferrous Food and Beverage Containers	1.7%	1.4%
Metals	Other Ferrous Metals	2.0%	1.6%
Metals	Other Non-Ferrous Scrap	1.4%	1.1%
Total Metals		**5.4%**	**4.5%**
Glass	Glass Non-Deposit Containers	2.6%	2.0%
Glass	Glass Deposit Containers	1.5%	1.6%
Glass	Other Glass/Mixed Cullet	0.6%	0.3%
Total Glass		**4.7%**	**3.9%**
Yard Waste	Small Yard Waste	8.0%	5.5%
Yard Waste	Large Yard Waste	0.0%	0.0%
Total Yard Waste		**8.0%**	**5.5%**
Food Waste	Food Waste	15.7%	13.5%
Total Food Waste		**15.7%**	**13.5%**
Wood	Non-Treated Wood	0.3%	3.4%
Wood	Treated Wood	1.7%	1.3%
Total Wood		**2.0%**	**4.7%**
Demolition/Renovation/Construction Debris	C/R/D Debris	1.5%	1.1%
Total Demolition/Renovation/Construction Debris			**1.1%**
Durables	Electrical And Household Appliances	1.8%	0.7%
Durables	Central Processing Units/Peripherals	0.0%	0.1%
Durables	Computer Monitors/TV'S	0.0%	0.0%
Durables	Cell Phones and Chargers	0.0%	0.0%
Durables	Other Durables	0.3%	0.4%
Total Durables		**2.0%**	**1.1%**
Textiles and Leathers	Textiles and Leathers	3.2%	4.6%
Total Textiles and Leathers			
Diapers	Diapers	2.9%	1.7%
Total Diapers		**2.9%**	**1.7%**

County of Maui Waste Composition (continued).

Material Group	Material	Percent Residential Waste Stream	Percent of Commercial Waste Stream
Rubber	Rubber	0.2%	0.3%
Total Rubber		**0.2%**	**0.3%**
HHW	Automotive Products	0.0%	0.0%
HHW	Paints and Solvent	0.0%	0.0%
HHW	Pesticides, Herbicides, Fungicides	0.0%	0.0%
HHW	Household Cleaners	0.0%	0.0%
HHW	Lead Acid Batteries	0.0%	0.0%
HHW	Other Batteries	0.5%	0.4%
HHW	Other HHW	0.2%	0.0%
HHW	Mercury Containing Products	0.0%	0.0%
Total HHW		**0.7%**	**0.5%**
Sharps	Sharps	0.1%	0.1%
Total Sharps		**0.1%**	**0.1%**
Other Organic	Other Organic	0.8%	0.7%
Total Other Organic		**0.8%**	**0.7%**
Other Inorganic	Other Inorganic	1.8%	1.5%
Total Other Inorganic		**1.8%**	**1.5%**
Fines/Super Mix	Fines/Super Mix	3.6%	2.5%
Total Fines/Super Mix		**3.6%**	**2.5%**
Other	Other	0.3%	0.3%
Total Other		**0.3%**	**0.3%**
GRAND TOTAL		**100.0%**	**100.0%**

County of Kaua'i Waste Composition (Cascadia, 2017).

Table 5. Detailed Composition, Overall Kaua'i Countywide Waste Composition, 2016

Material	Estimated Percent	Estimated Tons	Material	Estimated Percent	Estimated Tons
Paper	**18.4%**	**15,441**	**Other Organics**	**18.0%**	**15,107**
Uncoated Corrugated Cardboard	4.4%	3,674	Leaves and Grass	4.3%	3,579
Kraft Paper Bags	1.4%	1,149	Prunings and Trimmings	1.9%	1,585
Newspaper	0.8%	629	Branches and Stumps	0.1%	64
White Ledger Paper	1.3%	1,096	Manures	0.0%	0
Mixed Paper	4.1%	3,472	Textiles	3.0%	2,525
Aseptic and Gable Top Containers	0.4%	323	Carpet	0.6%	508
Compostable Paper	4.4%	3,711	Sewage Sludge	4.8%	3,985
Non-Recyclable Paper	1.7%	1,386	Non-Recyclable Organic	3.4%	2,861
Plastic	**11.5%**	**9,595**	**Inerts and Other C&D**	**23.7%**	**19,815**
PETE Containers - HI-5	0.4%	375	Concrete	1.3%	1,072
PETE Containers - Non-HI-5	0.3%	246	Asphalt Paving	0.0%	3
HDPE Containers - HI-5	0.1%	122	Asphalt Roofing	1.9%	1,566
HDPE Containers - Non-HI-5	0.5%	430	Clean Lumber	5.0%	4,167
Plastic Containers #3-#7	1.1%	958	Treated Lumber	2.9%	2,467
Plastic Grocery and Other Merchandise Bags	0.0%	41	Other Wood Waste	6.2%	5,157
Agricultural Film Plastic	0.1%	80	Gypsum Board	3.4%	2,821
Other Clean Film	0.5%	385	Rock, Soil and Fines	1.7%	1,395
Non-Recyclable Film Plastic	4.1%	3,407	Non-Recyclable Inerts and Other	1.4%	1,166
Durable Plastic Items	1.9%	1,605			
Expanded Polystyrene Food Serviceware	0.4%	364	**Electronics and Appliances**	**1.7%**	**1,446**
Other Expanded Polystyrene	0.3%	236	Covered Electronic Devices	0.2%	138
Non-Recyclable Plastic	1.6%	1,345	Non-Covered Electronic Devices	0.5%	387
			Major Appliances	0.0%	0
Glass	**2.8%**	**2,332**	Small Appliances	1.1%	921
Glass Bottles and Containers - HI-5	0.9%	761			
Glass Bottles and Containers - Non-HI-5	1.3%	1,083	**Household Hazardous Waste (HHW)**	**0.7%**	**626**
Non-Recyclable Glass	0.6%	488	Paint	0.0%	38
			Empty Aerosol Containers	0.1%	70
Metal	**3.9%**	**3,240**	Vehicle and Equipment Fluids	0.0%	0
Tin/Steel Cans	0.5%	438	Used Oil	0.0%	2
Bi-Metal Cans HI-5	0.1%	69	Batteries	0.1%	109
Other Ferrous	1.3%	1,060	Mercury-Containing Items - Not Lamps	0.0%	0
Aluminum Cans - HI-5	0.3%	228	Lamps - Fluorescent and LED	0.0%	8
Aluminum Cans - Non-HI-5	0.1%	78	Remainder/Composite Household Hazardous	0.5%	399
Other Non-Ferrous	0.6%	530			
Remainder/Composite Metal	1.0%	838	**Special Waste**	**1.7%**	**1,415**
			Ash	0.2%	130
Food	**10.3%**	**8,635**	Treated Medical Waste	0.0%	4
Retail Packaged Food - Meat	0.5%	432	Bulky Items	0.4%	335
Retail Packaged Food - Non-Meat	2.8%	2,361	Tires	0.0%	9
Unpackaged Food - Meat	0.9%	787	Remainder/Composite Special Waste	1.1%	937
Other Packaged Food - Meat	0.6%	522			
Unpackaged Food - Non-Meat	4.3%	3,597	**Mixed Residue**	**7.3%**	**6,089**
Other Packaged Food - Non-Meat	1.1%	936	Mixed Residue	7.3%	6,089
			Totals	**100.0%**	**83,740**
			Samples	**162**	

County of Hawaii Waste Composition (Parametrix, 2019 which used a 2008 waste characterization; note that the Draft watermark is part of the cited document).

EXHIBIT A-1

Composition Estimates: Total County

	Tons Disposed	Percent of Total		Tons Disposed	Percent of Total
Paper	**47,130**	**22.4%**	**Construction and Demolition**	**46,702**	**22.2%**
Cardboard	16,182	7.7%	Concrete	5,128	2.4%
Bags	723	0.3%	Asphalt Paving	2,212	1.1%
Newspaper	4,193	2.0%	Asphalt Roofing	381	0.2%
White Ledger	1,540	0.7%	Clean and Treated Lumber	22,984	10.9%
Colored Ledger	280	0.1%	Gypsum Board	1,471	0.7%
Computer	92	0.0%	Rocks and Soil	1,707	0.8%
Office	1,510	0.7%	R/C Demo	12,819	6.1%
Magazines	2,424	1.2%	**Household Hazardous**	**527**	**0.3%**
Directories	109	0.1%	Paint	171	0.1%
Miscellaneous	8,634	4.1%	Vehicle Fluids	20	0.0%
R/C Paper	11,443	5.4%	Oil	54	0.0%
Glass	**4,592**	**2.2%**	Batteries	117	0.1%
Clear Containers	1,476	0.7%	R/C Hazardous	165	0.1%
Green Containers	1,296	0.6%	**Special**	**6,762**	**3.2%**
Brown Containers	1,024	0.5%	Ash	93	0.0%
Other Containers	307	0.1%	Sewage Sludge	0	0.0%
Flat Glass	160	0.1%	Industrial Sludge	2,826	1.3%
R/C Glass	329	0.2%	Treated Medical	139	0.1%
Metal	**16,388**	**7.8%**	Bulky Items	2,177	1.0%
Aluminum Cans	565	0.3%	Tires	1,124	0.5%
Tin Cans	1,525	0.7%	R/C Special	404	0.2%
Ferrous	7,441	3.5%	**Mixed**	**997**	**0.5%**
Nonferrous	504	0.2%	Mixed Residue	997	0.5%
White Goods	742	0.4%			
R/C Metal	5,611	2.7%			
Plastic	**17,482**	**8.3%**			
#1 Containers	1,067	0.5%			
#2 Containers	882	0.4%			
Other Containers	818	0.4%			
Film	6,170	2.9%			
Durable	4,002	1.9%			
R/C Plastic	4,543	2.2%			
Organics	**69,448**	**33.1%**			
Food	34,230	16.3%			
Textiles	5,485	2.6%			
Leaves and Grass	6,160	2.9%			
Prunings	7,057	3.4%			
Stumps	2,637	1.3%			
Crop Residue	3	0.0%			
Manure	0	0.0%			
R/C Organic	13,875	6.6%			
Total Tons	210,030				
Sample Count	100				

Appendix G: RNG Potential from combustible components of the landfilled MSW stream by county (comprehensive table)
(US customary units this page. Version with SI units on next page)

	Energy Content-HHV* (Btu/dry-lb)	Moisture* (%wb)	Maui			Kauai			Hawaii			Honolulu		
			Landfilled		RNG Potential** (million therms)	Landfilled		RNG Potential** (million therms)	Landfilled		RNG Potential** (million therms)	Landfilled		RNG Potential** (million therms)
			(wet tons)	(dry tons)		(wet tons)	(dry tons)		(wet tons)	(dry tons)		(wet tons)	(dry tons)	
Paper/Cardboard	7,640	10	81,360	73,224	6.0	16,943	15,249	1.3	56,753	51,078	7.0	11,044	9,940	1.4
C&D Lumber	8,310	12	3,296	2,901	0.3	12,984	11,426	1.7	27,616	24,302	3.6	5,302	4,666	0.7
Prunings, trimmings, branches, stumps	8,170	40	4,547	2,728	0.2	1,842	1,105	0.2	11,908	7,145	1.1	99	60	0.01
Other Organics	3,810	4	7,209	6,920	0.3	7,551	7,249	0.5	16,722	16,053	1.1	2,823	2,710	0.2
Leaves and Grass	6,450	60	14,739	5,896	0.4	3,960	1,584	0.2	7,347	2,939	0.3	2,938	1,175	0.1
Biomass Components (paper, wood, and other but NOT food)			**111,151**	**91,669**	**7.2**	**43,279**	**36,612**	**3.8**	**120,346**	**101,517**	**13.2**	**22,207**	**18,551**	**2.4**
All non-Film Plastic	9,480	0.2	18,152	18,115	1.9	6,262	6,249	1.1	13,681	13,654	2.3	2,625	2,620	0.4
Film Plastic	19,400	0.2	13,774	13,747	2.9	4,328	4,319	1.5	7,347	7,333	2.6	2,142	2,138	0.7
Textiles	8,310	10	8,897	8,007	0.7	3,315	2,983	0.4	6,587	5,929	0.9	1,673	1,506	0.2
Plastics and Textiles (Non-Renewable Carbon Compounds)			**40,823**	**39,870**	**5.5**	**13,904**	**13,552**	**3.0**	**27,616**	**26,916**	**5.8**	**6,440**	**6,264**	**1.4**

Notes:
* Energy and moisture contents from Tchobanaglous, G., Theisen, H. and Vigil, S.(1993),"Integrated Solid Waste Management", Chapter 4, McGraw-Hill, New York
& Themelis, N. J., Kim, Y. H., and Brady, M. H. (2002). "Energy recovery from New York City municipal solid wastes." Waste Management & Research, 20(3), 223-233
** Assumes 90% recovery & prep yield of material and 60% energy conversion efficiency (GTI, 2019; Alamia et al., 2017)

RNG Potential from combustible components of the landfilled MSW stream by county (comprehensive table – SI Units)

	Energy Content-HHV* (MJ/dry-kg)	Moisture* (%wb)	Maui Landfilled (wet tonnes)	Maui Landfilled (dry tonnes)	Maui RNG Potential** (TJ)§	Kauai Landfilled (wet tonnes)	Kauai Landfilled (dry tonnes)	Kauai RNG Potential** (TJ)§	Hawaii Landfilled (wet tonnes)	Hawaii Landfilled (dry tonnes)	Hawaii RNG Potential** (TJ)§	Honolulu Landfilled (wet tonnes)	Honolulu Landfilled (dry tonnes)	Honolulu RNG Potential** (TJ)§
Paper/Cardboard	17.8	10	73,810	66,429	637	15,371	13,834	133	51,486	46,337	741	10,019	9,017	144
C&D Lumber	19.3	12	2,990	2,631	27	11,779	10,365	180	25,053	22,047	384	4,810	4,233	74
Prunings, trimmings, branches, stumps	19.0	40	4,125	2,475	25	1,671	1,002	17	10,803	6,482	111	90	54	1
Other Organics	8.9	4	6,540	6,278	30	6,850	6,576	52	15,170	14,563	116	2,561	2,459	20
Leaves and Grass	15.0	60	13,371	5,349	43	3,592	1,437	19	6,666	2,666	36	2,665	1,066	14
Biomass Components (paper, wood, and other but NOT food)			**100,836**	**83,162**	**764**	**39,262**	**33,214**	**402**	**109,178**	**92,095**	**1,388**	**20,146**	**16,829**	**253**
All non-Film Plastic	22.1	0.2	16,467	16,434	196	5,680	5,669	113	12,412	12,387	246	2,381	2,376	47
Film Plastic	45.1	0.2	12,496	12,471	304	3,926	3,918	159	6,666	6,652	270	1,943	1,940	79
Textiles	19.3	10	8,071	7,264	76	3,007	2,707	47	5,976	5,378	94	1,518	1,366	24
Plastics and Textiles (Non-Renewable Carbon Compounds)			**37,034**	**36,169**	**575**	**12,614**	**12,294**	**319**	**25,053**	**24,418**	**610**	**5,843**	**5,682**	**150**

Notes:

* Energy and moisture contents from Tchobanaglous, G., Theisen, H. and Vigil, S.(1993),"Integrated Solid Waste Management", Chapter 4, McGraw-Hill, New York

& Themelis, N. J., Kim, Y. H., and Brady, M. H. (2002). "Energy recovery from New York City municipal solid wastes." Waste Management & Research, 20(3), 223-233

** Assumes 90% recovery & prep yield of material and 60% energy conversion efficiency (GTI, 2019; Alamia et al., 2017).

§ TJ (terajoule) = 10^{12} J = 1000 GJ

Appendix H: SI versions of Tables 4, 5, 8,9,10,11, 12, and 14 in body of report

Table 4-SI. Salient characteristics of WWTPs in Hawaii receiving daily wastewater flows greater than 3,785 m^3 per day.

Name	County/ Ownership	Wastewater Received[a] (average m^3 d^{-1})	Anaerobic Digester	Biogas Production (m^3 d^{-1})	Methane Concentration (%)	Methane Production (m^3 d^{-1})	Methane Production (TJ y^{-1})	Biogas Use[c]
Sand Island	Honolulu/public	287,700	Yes	9,570	60 (assumed)	5,740	78	C, D
Honouliuli	Honolulu/public	97,300	Yes	8,500	60	5,100	69	B, C, D
Kailua	Honolulu/public	61,700	Yes	2,950 [b]	60 (assumed)	1,770 [b]	24 [b]	C, D
Waianae	Honolulu/public	14,400	Yes	800	50 to 70	480	6.5	D
East Honolulu	Honolulu/private	16,700	Yes	1,050	57	600	8.1	D
Schofield	Honolulu/private	9,100	Yes	450	60	270	3.7	C, D
Lahaina	Maui/public	15,900	No	na	na	na	na	na
Wailuku-Kahului	Maui/public	14,800	No	na	na	na	na	na
Kihei	Maui/public	13,600	No	na	na	na	na	na
Hilo	Hawaii/public	15,900	Yes	765[b]	60 (assumed)	456[b]	6.2[b]	D
Kealakehe	Hawaii/public	6,400	No	na	na	na	na	na
Lihue	Kauai/public	4,200	Yes	200[b]	60 (assumed)	120[b]	1.6[b]	D

[a] Source, Wastewater and Clean Water Branches, Department of Health, State of Hawaii

[b] Assumes 28.7 m^3 CH_4 per 1,000 m^3 WW based on the averaged operating data from Sand Island, Honouliuli, Waianae, East Honolulu, and Schofield WWTPs

[c] B – RNG (Hawaii Gas), C – combusted for process heat (e.g. biosolids drying or digester heating), D – balance flared

Table 5-SI. Summary of 2018 data on landfills in the State of Hawaii (LMOP, 2020)

Landfill Name	Landfill Owner Organization(s)	Year Opened	Closure Year	Current Status	Waste in Place (Mg)	Waste in Place Year	LFG Collection System In Place?	LFG Collected[a] (m^3/d)	LFG Flared[a] (m^3/d)	Current LFG Project Status [b]
Central Maui	Maui County	1987	2039	Open	4,910,000	2018	Yes	32,100	32,100	Candidate
Hana Landfill	Maui County	1969	2079	Open	112,900	2008	No			FP
Kailua Landfill	Hawaii County	1975	1993	Closed	453,500		No			LP
Kalamaula Landfill	Maui County	1970	1993	Closed	74,000	1993	No			LP
Kaneohe MC Air Station Landfill	United States Marine Corps	1978	2024	Open			No			Unknown
Kapaa	C&C of Honolulu	1955		Closed	4,082,000	2000	?			LP
Kapaa and Kalaheo Sanitary Landfills	C&C of Honolulu	1970	1995	Closed	5,300,000	1995	Yes	11,200	11,200	Shutdown
Kekaha Phases I & II	County of Kauai	1953	2021	Open	2,503,000	2018	Yes	17,800	17,800	Candidate
Lanai Landfill	Maui County	1969	2020	Open	165,900	2008	No			FP
Naiwa Landfill, Molokai	Maui Co	1993		Open	82,400	2008	No			FP
Olowalu Landfill	Maui County	1967	1992	Closed	235,600	1992	No			LP
Palailai Landfill	Grace Pacific Co.	1974	1988	Closed	2,581,000	1988	Yes	1,560	1,560	LP
South Hilo Sanitary Landfill (SHSL)	Hawaii County	1969	2020	Open	2,842,000	2018	No			Candidate
Waimanalo Gulch Landfill & Ash Monofill	C&C of Honolulu	1989	2038	Open	11,030,000	2018	Yes	29,100	29,100	Candidate
West Hawaii Landfill/Pu`uanahulu	Hawaii County	1993	2054	Open	2,405,000	2018	Yes	10,800	10,800	Candidate

[a] LFG volume reported at 60 °F (15.6 °C) and 1 atm pressure

[b] The LMOP website "defines a candidate landfill as one that is accepting waste or has been closed for five years or less, has at least one million tons of waste, and does not have an operational, under-construction, or planned project; candidate landfills can also be designated based on actual interest by the site." FP = Future Potential, LP = Low Potential

Table 8-SI. Annual food waste estimates for Hawaii.

Source	Generated (Mg y^{-1})	Per Capita (kg ca^{-1} y^{-1})	Recycled ((Mg y^{-1})	% Recycled	Defacto Population	Data Year	Comments
Belt Collins Hawaii (2000)	147,500	111	13,890	9.4	1,332,000	1999	Household and businesses
Turn et al. (2002)	162,600	120			1,353,000	2002	Household and businesses
Okazaki et al. (2008)	335,800	240	86,310	25.7	1,400,000	2005	Food Establishments
Loke & Leung (2015)	225,700	154			1,468,000	2010	Consumer, Distr., retail

Table 9-SI. County food waste disposal and associated methane potential via AD by county

	2015	2019
Maui ISWMP (2008), OSWM (2016), OSWM (2020)		
Landfill Disposal (Mg, MSW including food waste)	166,132	202,552
Food Waste Disposal (Mg)	24,036	29,305
Food Waste Recovered for AD (Mg, assumes 50% recovery)	12,018	14,653
Potential CH_4 production from AD (million m^3 CH_4 y^{-1}) *	4.2	5.1
Potential CH_4 production from AD (TJ CH_4 y^{-1})	155	189
Kauai 2016 Waste Characterization (2008), OSWM (2016), OSWM (2020)		
Landfill Disposal (Mg, MSW including food waste)	73,921	83,518
Food Waste Disposal (Mg)	7,629	8,619
Food Waste Recovered for AD (Mg, assumes 50% recovery)	3,815	4,310
Potential CH_4 production from AD (million m^3 CH_4 y^{-1}) *	1.3	1.5
Potential CH_4 production from AD (TJ CH_4 y^{-1})	50	56
Hawaii County ISWMP & 2008 Waste Characterization, (2008), OSWM (2016), OSWM (2020)		
Landfill Disposal (Mg, MSW including food waste)	162,383	229,798
Food Waste Disposal (Mg)	26,468	37,457
Food Waste Recovered for AD (Mg, assumes 50% recovery)	13,234	18,729
Potential CH_4 production from AD (million m^3 CH_4 y^{-1}) *	4.6	6.5
Potential CH_4 production from AD (TJ CH_4 y^{-1})	171	242
Honolulu- City & County ISWMP & 2017 Waste Characterization		
Landfill Disposal (Mg, MSW including food waste)	58,141	44,120
Food Waste Disposal (Mg)	11,691	8,872
Food Waste Recovered for AD (Mg, assumes 50% recovery)	5,846	4,436
Potential CH_4 production from AD (million m^3 CH_4 y^{-1}) *	2.0	1.5
Potential CH_4 production from AD (TJ CH_4 y^{-1})	75	57
Combined (Maui, Kauai, Hawaii, Honolulu)		
Landfill Disposal (Mg, MSW including food waste)	460,577	559,989
Food Waste Recovered for AD (Mg, assumes 50% recovery)	34,912	42,127
Potential CH_4 production from AD (million m^3 CH_4 y^{-1}) *	12.1	14.6
Potential CH_4 production from AD (TJ CH_4 y^{-1})	451	543
* Assumes food waste is 70% moisture, volatile solids comprise 85% of total solids, and specific gas production of 346 m^3 CH_4 per tonne volatile solids (Charbonnet et al., 2019; Fitamo et al., 2016)		

Table 10-SI. Annual landfilled, and RNG potential, of combustible components of MSW by county.

	Maui		Kauai		Hawaii		Honolulu	
	Landfilled (Mg)	RNG Potential* (TJ)	Landfilled (Mg)	RNG Potential* (TJ)	Landfilled (Mg)	RNG Potential* (TJ)	Landfilled (Mg)	RNG Potential* (TJ)
Non-Food Biomass Components	100,814	760	39,254	401	109,154	1393	20,142	253
Plastics and Textiles	37,026	580	12,611	317	25,048	612	5,841	148
Totals	137,840	1,340	51,865	717	134,202	2,005	25,983	401

*RNG potential based on moisture, energy content, assumed 90% material recovery & preparation yield, and 60% conversion efficiency from Tchobanaglous et al., 1993; Themelis et al., 2002; GTI, 2019; Alamia et al., 2017

Table 11-SI. Summary of area (hectares) in the agricultural land use district in the State of Hawaii.

	Agricultural Land Use District (2015 data)				
Island	Total	LCC 1-4	LCC 5-6	LCC 1-4 Slope ≤20%	LCC 5-6 Slope ≤20%
Kauai	58,416	31,448	5,664	27,171	2,955
Oahu	48,882	17,771	2,074	16,836	896
Molokai	44,836	17,098	5,433	16,285	3,609
Lanai	18,054	8,837	741	8,521	590
Maui	95,194	41,089	22,252	35,428	11,618
Hawaiʻi	478,878	190,042	67,853	156,233	54,357
Total	744,259	306,285	104,019	260,475	74,026
LCC – land capability class					

Table 12-SI. Summary of Hawaii agricultural land use (acres) in 2015 (Melrose et al., 2015).

Island	Total	Crops	Commercial Forestry	Pasture
Kauai	25,594	7,918	705	16,970
Oahu	16,518	9,036	11	7,472
Molokai	16,938	1,454	-	15,484
Lanai	26	26	-	-
Maui	61,435	17,534	13	43,887
Hawaiʻi	249,073	16,223	8,523	224,327
Total	369,584	52,191	9,252	308,140

Table 14-SI. RNG potential summary (TJ per year) for resources in Hawaii

Resource Type	Maui	Kauai	Hawaii	Honolulu	State Total
Livestock Manure	*	*	*	*	
Wastewater Treatment Plants	-	2.1	6.3	190	200
Landfill Gas	227	104	60.9	260	652
Food Waste portion of MSW	189	55.6	241	57.2	543
Combustible portion of MSW	1,339	721	1,997	402	4,460
CDW	-	-	-	3,007	3,007
Agricultural and Forestry Residues	‡	‡	‡	‡	‡
Energy Crops	§	§	§	§	§
Totals ⸙	>1,755	>883	>2,311	>3,904	>8,863

* Insufficient number and size of animal feeding operations to justify methane production and recovery

‡ Insufficient available agricultural residues and ongoing forestry harvesting residues

§ Underutilized agricultural land resources in the State could support substantial RNG production from dedicated energy crops (~260 to 520 GJ per hectare per year)

⸙ Totals would be larger with implementation of energy crop based RNG production