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Renewable Energy in Ukraine Technical Report:

Biogas

One of five technical reports on Renewable Energy for the USELF Strategic Environmental Review

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RENEWABLE ENERGY IN UKRAINE TECHNICAL REPORT: BIOGAS

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RENEWABLE ENERGY IN UKRAINE TECHNICAL REPORT: BIOGAS

1. INTRODUCTION

The purpose of this technical report is to provide the USELF Strategic Environmental (SER) team with a representative scenario for biogas development in Ukraine as the team develops the SER report. The analysis examines potential locations, technologies and operating conditions for the biogas scenario. It focuses on the technical constraints associated with the availability of the resource and the technologies that employ the resource, but does not address environmental and socioeconomic constraints that will be discussed in the SER separately. This is not intended to preclude or limit the future development of other technologies that have not been identified here for review.

The report is organized into two sections:

- Resource and Potential
- Technology Characteristics

Section 2 (Resource and Potential) of the report provides the SER process with country-wide background of the availability and quantity of the biogas resource, as well as potential locations or higher concentrations of biogas resources in Ukraine.

Section 3 (Technology Characterstics) describes the technologies that employ the resource for electricity production and details the performance characteristics, emissions, interconnection and operations and maintenance needs of the technology, as well as the availability of the technology components in Ukraine. The section also examines typical site considerations and construction activities associated with biogas projects as inputs to the SER report.

The two primary biogas project fuel sources examined herein are generated from the anaerobic digestion of animal waste and from the decomposition of organic waste in landfills.

2. RESOURCE AND POTENTIAL

2.1 Landfill Gas

Landfill gas (LFG) is produced by the natural decomposition of the organic matter contained in municipal landfills. Gas production at a landfill is primarily dependent on both the depth and the age of waste in place and the amount of precipitation received by the landfill. In general, LFG recovery may be economically feasible at sites that have more than one million tons of waste in place, more than 10 hectares available for gas recovery, waste depth greater than 12 meters, and at least 60 centimeters of precipitation annually. It is necessary for a landfill to be covered and to have a gas collection system in order to capture and utilize the methane. The life of resource landfill site for LFG production is limited. After waste deliveries to a landfill cease and the landfill is capped, LFG production will decline. This decline typically follows a first order decay.

LFG is composed of 40 to 60 percent methane on a volumetric basis. As a greenhouse gas, methane has 25 times higher global warming potential than carbon dioxide over a 100 year time period. Methane readily escapes into the atmosphere at landfills without proper methane collection systems in place. Collecting the gas and converting the methane to carbon dioxide through combustion greatly reduces the potency of LFG as a source of greenhouse gas emissions.

In Ukraine 10 to 12 M tonnes of MSW are generated every year (Matveev, Y, 2010), 95% of this waste is disposed in landfills. There are approximately 700 landfill sites, of which 80% do not have measures in place to control emissions to air and water (ECE, 1999), thus resulting in severe odour problems and an unnecessary contribution to global warming. Landfills in Ukraine lack modern landfill practices, including the use of daily cover, proper compaction techniques, leachate collection and gas collection, and therefore do not generate electricity or utilize the thermal energy.

It has been estimated that of the 700 operational landfills, only 100 have the potential for recovery and utilization of the LFG generated, representing 8.79 PJ and GHG savings of 6.0M tCO2e (Matveev, Y, 2010). However, only the largest landfill sites in the country are practical to develop for electricity generation, since the site must produce sufficient amount of LFG for 10-15 years in order to supply fuel to power generators economically. They are associated with cities with higher populations which are directly correlated with waste generation and amount of waste in place for landfill gas production (see Figure 2-1). Appendix A also provides a more detailed breakdown of candidate sites.

The total for these higher probability landfill sites is about 48 MW but range from 600 kW to over 5 MW, depending on the site. The capacity potential estimate is based on the waste in place data, but LFG production vary extensively depending on factors such as age of landfill, annual deposits, precipitation in the area, composition of landfill, depth of landfill, and collection system. Without modeling each landfill site separately, an approximation using waste in place is used to estimate capacity potential of these sites, except where site specific feasibility studies were developed through the Global Methane Initiative.

Several *"Methane 2 Markets"* (M2M) projects are under consideration / development under the auspices of the Global Methane Initiative. These projects, listed in Table 2-1, have been investigated for power and heat conversion potential.

Table 2-1. M2M Feasibility Studies.

Project Name	Status
Chernivtsi Landfill	Idea
Dnepropetrovsk Landfill	Idea
Donetsk Landfill	Idea
Ordzhonikidzevsky Landfill	Idea
Khelmintsky Landfill	Completed
Lviv Landfill	Completed
Closed Mariupol Landfill	Completed

Source: http://www.globalmethane.org/projects/index.aspx?expo=newdelhi

2.2 Animal Manure

Using animal manure in anaerobic digesters to produce methane is a good alternative to current practices of handling animal manure in Ukraine, which include spreading on open fields, because of the opportunity to capture energy and reduce greenhouse gas emissions. A significant percentage of the cattle (66%) and pigs (58%) are reared in private households and small scale farms and therefore the collection of manure in an economic manner is an issue to be addressed.

Manure, particular from commercial dairy operations, provides substantial opportunity for biogas production. Dairy manure offers a consistent and reliable substrate with high availability. Other sources of manure include pig and poultry farming operations. Manure creates stable process conditions and liquid slurry manure management systems can allow for ease of waste handling. In general, large dairy operations with high animal head counts represent greatest potential as economies of scale greatly favor these operations. Facilities utilizing concentrated animal feeding operations (CAFOs) may also capitalize on economic advantages associated with collection of manure. Co-digestion (utilizing multiple substrates, for example animal manure mixed with food waste) offer opportunities for increasing biogas production.

Based on data from the Institute for Economic Research and Policy Consulting, typical biogas production from cattle, pig and poultry is identified in Table 2-2. The Institute estimates the biogas potential from animal manure is 2,536,000 m^3/day.

Table 2-2. Biogas Production Estimates from Animal Manure.

	Headcount (000)*	**VS per head (kg/day)****	**VS reduced (%)**	**Biogas yield per kg of VS, (m^3/day)**	**Total Biogas yield, (000) (m^3/day)**
Cattle	1,720.1	0.88-5.29	35	0.4	824.6
Pigs	2,730.9	0.041-0.93	40	0.8	461.7
Poultry	85,720	0.036	45	0.9	1,249.8
Total					***2,536.1***

Source: Kuznetsova, A. and Kutsenka, K., 2010. “Biogas and “green tariffs” in “Ukraine – A profitable investment?” German–Ukrainian Policy Dialogue in Agriculture” Institute for Economic Research and Policy Consulting.

Notes:
*2008 figures.
**Range reflects young to mature animals.

The maps shown on Figures 1-2 through 1-4 depict the population of cows, pigs, and poultry by region in Ukraine. Areas of greater livestock populations are more likely candidates for biogas development.

Based on the biogas production estimates developed, a minimum size cattle operation would require about 1350 head of adult cattle to support daily methane production of 1000 m^3 per day. For pigs, the headcount would require about 3400 in one location to support 1000 m^3 per day of biogas production. Poultry operations would need to have populations of over 68,000 poultry in a local area, though poultry litter can be transported more readily to a centralized location for processing. These would need to be industrial scale operations.

The maximum potential of all of the animal waste is equal to a total of 634 MW, which assumes 4000 cubic meters per day of biogas per MW of generation capacity. However, not all of this could be realistically developed due to the economics of smaller farms. However, there is no data available to assess the breakdown of farm sizes in Ukraine. As a conservative estimate, it is assumed that the maximum development is about 25% of the maximum potential, which is about 160 MW.

3. TECHNOLOGY CHARACTERISTICS

This report section provides an overview of biogas technologies that have been identified in the SER scoping report, namely:

- Landfill Gas
  - Microturbines
  - Internal Combustion Engines
  - Simple Cycle Gas Turbines
- Animal Manure Digestion
  - Internal Combustion Engines

3.1 LFG Projects

LFG energy recovery is currently regarded as one of the more mature and successful waste-to-energy technologies. There are more than 600 LFG energy recovery systems installed in 20 countries. A landfill gas project is usually located at or near an existing landfill site. The landfill needs to be partially or completely covered in order to capture the methane.

A LFG project is comprised of a LFG collection system to extract trapped gases in the landfill, a gas cleaning system to remove, at a minimum, sediment and moisture from the gas, and a power generation system to combust the gas to generate electricity and heat. There may be an additional boiler to utilize the waste heat from the combustion for steam or hot water applications. Figure 3-1 depicts a typical modern LFG facility.

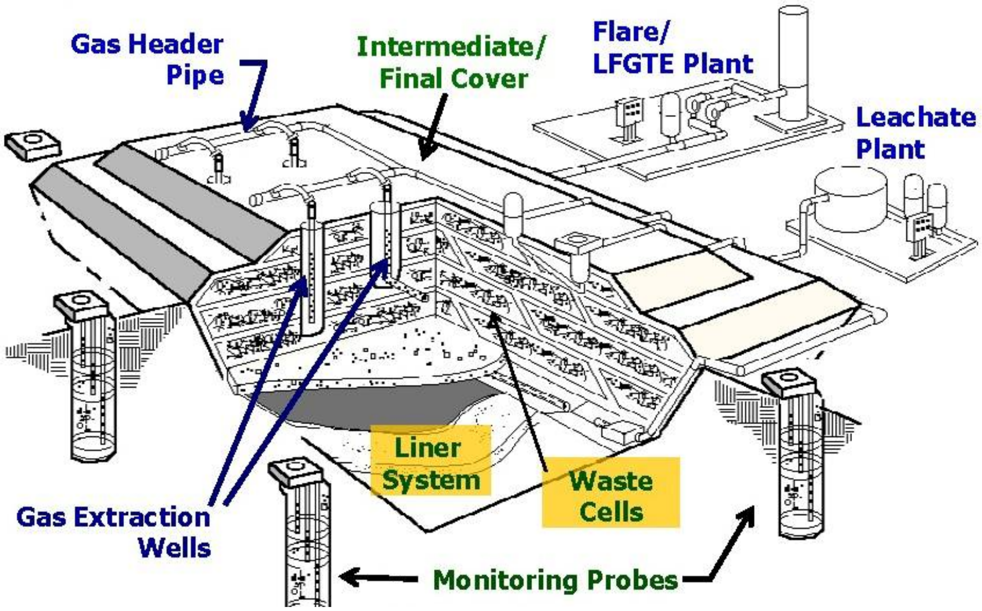


Figure 3-1. LFG Facility (courtesy US EPA).

A LFG collection system consists of multiple wellheads connected to lateral piping, which transports the gas to a main collection header, as shown in Figure 3-1. A blower is necessary to pull the gas from the collection wells into the collection header and convey the gas to downstream treatment and energy recovery systems. The size, type, and number of blowers needed depend on the gas flow rate and distance to downstream processes. There are also flares installed to control LFG emissions during energy recovery system startup and downtime and to control gas that exceeds the capacity of the energy conversion equipment.

Methane (45%-60%) and carbon dioxide (40%-60%) are the major constituents of LFG, although the gas often contains trace amounts of contaminants such as ammonia, hydrogen sulfide and siloxanes. The presence of contaminants can vary dramatically from landfill to landfill and depends upon the types of waste contained at the site. Raw gas from domestic waste is more likely to contain odiferous compounds such as terpenes and carbonyls. Raw gas from industrial waste contains the highest levels of arsenic. The total sulfur content of raw landfill gas is about half hydrogen sulfide, and half organic sulfides and thiols. Thus, depending on the types of contaminants found in the LFG and the type of energy conversion technology employed, some gas cleaning technologies may be needed at this stage. No separate odor controls are used. Hydrogen sulfide (H_2S) is an extremely reactive compound that forms an acidic solution with water in the gas processing equipment. The H_2S present in digester gas and LFG is the primary contributory factor to shortened usable life of many of the components in the biogas system. In addition, H_2S is a dangerous compound that can be lethal at concentrations above 700 ppm.

When left unchecked, these contaminants can increase the maintenance requirements of the equipment fueled by the gas, reduce equipment life, and prevent the gas from being suitable for pipeline injection. At a minimum, most primary processing systems include de-watering and filtration to remove moisture and particulates. It is common in new projects to remove water vapor or humidity in the LFG by using gas cooling and compression. LFG used for power generation, however, does not need to be cleaned to pipeline quality methane.

Power production from LFG facilities is limited by the LFG flow rate from the landfill due to the volume of waste in place and is typically less than 10 MW. The most common power conversion technologies to utilize LFG are reciprocating internal combustion engines or gas turbines. While power generation systems come in a range of sizes, for purposes of this assessment, the focus is on projects sized to utilize LFG directly on-site. Depending on the quantities of gas collected, emissions considerations, and project economics, technologies used for power generation include microturbines, reciprocating internal combustion engines (ICEs), and gas turbines.

Project lifespan for an LFG project is expected to be 15 years. Due to the productivity declines of landfills following being capped, electricity generation or capacity factor of projects decline over time.

(a) Reciprocating Internal Combustion Engines (100 kW – 3 MW)

Reciprocating internal combustion engines (ICEs) are by far the most common generating technology choice. A majority of facilities that generate electricity from LFG use this technology. The reasons for such widespread use are relatively low cost, high efficiency, and matches with the gas output of many landfills. Figure 3-2 shows an example of a reciprocating engine used for LFG energy generation.

Figure 3-2. Reciprocating Internal Combustion Engine Utilizing LFG.

The equipment typically consists of a skid-mounted package of a reciprocating engine, generator and a control panel. The popularity of engine generators is attributed to availability from multiple suppliers and familiarity of plant maintenance personnel with the engine, which resembles an automobile engine. The engine is typically a spark-ignited natural gas engine modified and de-rated for use with lower heating value gas. Because of its higher efficiency and lower air emissions, the engine generator of choice is typically a turbocharged lean-burn engine with a synchronous alternator. While most turbocharged engines require compressors to boost gas pressure to a sufficient level, the newer turbocharged, lean-burn (low emissions) engines that are available operate at gas pressures of only 14 to 35 kPa and compress the mixture with the turbocharger. Naturally aspirated engines are rarely specified, and are used only for very small units and where air emissions are not a concern. The engines typically operate at speeds from 900 to 1,200 rpm. Because most engine generators that are fueled with landfill and digester gas are employed in continuous duty applications, lower speed units are more often selected for long-term use. The primary emissions from these generators are nitrogen oxides (NO_x), sulfur oxides (SO_x), volatile organic compounds (VOCs), carbon monoxide (CO), carbon dioxide (CO_2) and particulate matter (PM). Emissions of SO_x are directly related to the sulfide content in LFG.

Multiple engine generator units are used to match gas production rates. Engine generators are typically housed in a building where they are readily accessible for servicing. Figure 3-3 identifies a typical reciprocating engine installation (1.6 MW). Cooling systems typically include heat exchangers to recover the heat from the jacket cooling water.

Figure 3-3. 1.6 MW LFG Reciprocating Engine Housing (DCO energy).

A 500 kW system typically requires around 5,000 m^3 of LFG a day, while a 3 MW system would require around 26,000 m^3 of LFG a day, depending on the gas quality and the heat rate of the installed equipment. Engines require periodic inspections and routine service, generally comprising minor adjustments and replacement of engine oil, filter, coolant, and spark plugs every 500 to 2,000 hours of operation. A minor overhaul (rebuilding cylinder head and turbocharger) is generally performed every 8,000 to 10,000 hours of operation. If siloxanes are present in the biogas and are not removed during the biogas treatment process, then the period for minor overhauls would likely be reduced to about 5,000 hours of operation. Major maintenance activities such as piston and liner replacement, crankshaft inspection, and bearing / seal replacements are generally performed every 30,000 to 72,000 hours of operation depending on the equipment and gas quality.

(b) Microturbines (30-250 kW)

Microturbines are attractive for small landfills that produce 400 – 3,000 m^3 of biogas per day, making on-site generation available to plants that formerly did not have this option. However, their application is limited due to the higher cost per unit of power capacity. It is a relatively new technology for on-site power generation at landfills, with the first commercial units installed in 1998. Microturbines are small gas combustion turbines that operate at very high speeds. They are modular packaged units consisting of air bearings and a single moving part that incorporates the turbine shaft and generator, and are typically rated at less than 300 kW. For the SER, projects of 30-250 kW are being considered as 300 kW+ systems are only recently becoming available on the market. Full systems include an enclosure for noise reduction, and weather enclosures are also available. The package includes both the microturbine generator and the cooling/heat recovery equipment.

Multiple units can be installed in parallel for higher capacity. Smaller units around the 30 kW size range are shown in Figure 3-4, and Figure 3-5 depicts a typical outdoor installation of such units complete with a gas cleaning skid, concrete foundation, and weather enclosure (roof).

Figure 3-4. Capstone Microturbines (30 kW).

Figure 3-5. Capstone Microturbines and Gas Treatment Skid Outdoor Installation.

A single unit has a small footprint, generally ranging from less than 1 m^2 for a 30 kW unit up to about 9 m^2 for a 250 kW unit. Benefits of microturbines include minimal noise and relatively low emissions compared to reciprocating ICEs and simple cycle gas turbines. All microturbines operating on gaseous fuels feature lean premixed combustor technology, which is not generally included in all larger turbines, and therefore they have potential for very low emissions. Microturbines are designed to achieve the objective of low emissions at full load; emissions are often higher when operating at part load. Gas cleaning will be required if any fuel contaminant in the LFG exceed manufacturer specifications. Siloxanes are generally less of a concern for microturbines than for reciprocating ICEs.

A 30 kW system typically requires as little as 400 m^3 of LFG a day, while a 250 kW system would require up to 3,000 m^3 of LFG a day, depending on the methane concentration of the biogas and the heat rate of the installed units.

Typical maintenance procedures include periodic inspections of the combustor and associated parts, the oil bearing, and replacement of the air and oil filters. Microturbines operating in environments with extremely dusty air may warrant more frequent air filter changes. An overhaul (replacement of the main shaft and inspection / replacement of the combustor) is generally done every 20,000 hours. Microturbines are generally operated with frequent startup cycles, at least one on-off cycle per day; there is some concern about the effects of this type of operation on component durability.

(c) Simple Cycle Gas Turbines (3-10 MW)

At larger landfill sites with higher levels of LFG production, around 30,000 m^3 per day or greater, gas turbine generators can be used. Though available in unit sizes from about 1 MW to nearly 50 MW, for purposes of the SER gas turbines 3 MW to 10 MW are examined. Gas turbines are fairly tolerant of some contaminants in biogas. Fuel contaminants such as ash, alkalis (sodium and potassium), and sulfur result in alkali sulfate deposits, which impede flow, degrade performance, and cause corrosion in the turbine hot section.

A turbine generator unit consists of a gas combustion turbine connected to a generator through speed reducing gearboxes. The unit is typically packaged on skids (modular mounting hardware), with individual weather protective and sound attenuation enclosures.

Performance declines at higher ambient temperatures. Combustion turbines are available to be configured to combust gas of relatively low energy content such as landfill gas that is not of pipeline quality. In addition to the turbine generator package, another skid-mounted module may be included with support equipment. The emissions from gas turbines are generally higher than for microturbines but lower than reciprocating ICEs.

Daily maintenance requirements generally include visual inspection of filters and general equipment conditions. Routine inspections are required every 4,000 hours to insure that the turbine is free of excessive vibration due to worn bearings, rotors, and damaged blade tips. An overhaul is generally needed every 25,000 to 50,000 hours depending on service and is typically a complete inspection and rebuild of components to restore the gas turbine to nearly original or current (upgraded) performance standards. Alternatively the owner may elect to replace the turbine equipment in whole with new equipment.

3.2 Animal Manure Digestion Projects

Anaerobic digestion (AD) is defined as the decomposition of biological wastes by micro-organisms, usually under wet conditions, in the absence of air (oxygen) to produce a gas comprising mostly methane and carbon dioxide. Digesters can be found at or near large animal farm operations for direct access to material. A typical animal manure anaerobic digester is pictured in Figure 3-6.

Figure 3-6. Dairy Manure Anaerobic Digestion Facility.

There are many types of digesters that are intended for use with wastes of specific characteristics. The types of agricultural digesters available include the following. In Europe the most common digestors are complete mix.

- **Covered Lagoon:** Large, lined, earthen lagoon with full or partial cover for biogas collection.

Figure 3-7. Covered Lagoon Reactor (courtesy PSU).

- **Plug Flow:** Straight or looped tanks covered for biogas collection. Tanks are configured in 3.5:1 to 5:1 length to width ratio per USDA-NRCS Biogas Interim Standards. Minimum depth of eight feet.

Figure 3-8. Plug Flow Reactor (courtesy PSU).

- **Complete Mix:** Metal or concrete tank with round or square footprint and covered for biogas collection. Includes agitating systems to mix the waste. Minimum depth of eight feet. This is the more prevalent system used in Europe.

Figure 3-9. Complete Mix Reactors - 526 kW plant (courtesy Biogas Nord).

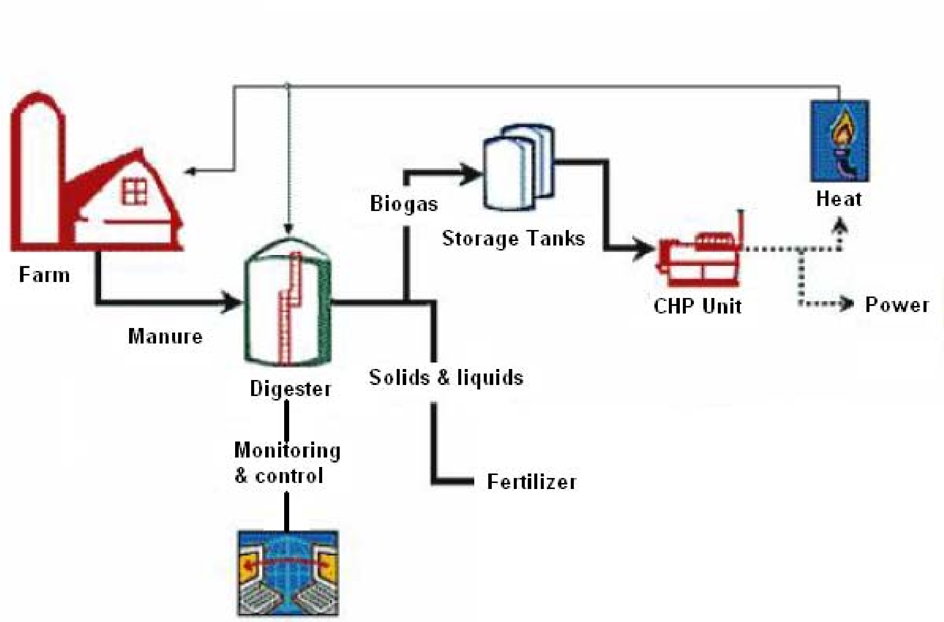


Figure 3-10. Example Process Flow Diagram for Animal Manure Digestion. (Courtesy: Composting & Recycling Consultants Ireland)

A typical AD processes contains up to four stages – pretreatment, sterilization, digestion, and post-digestion.

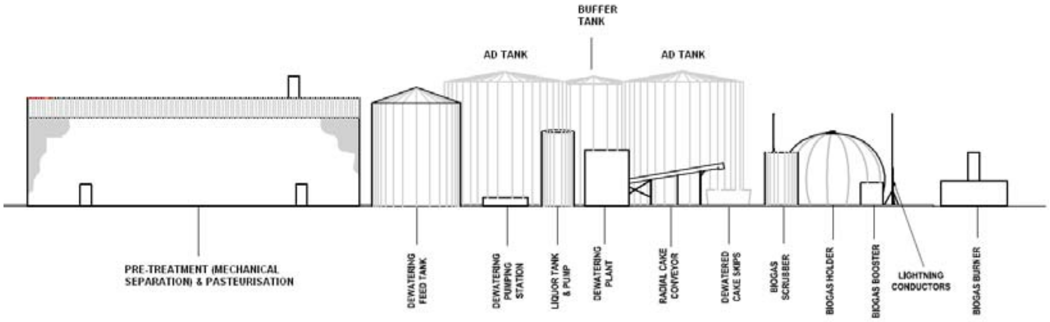


Figure 3-11. Plant Layout for a Typical AD Facility

Pretreatment: In the pre-treatment stage, waste is prepared into a suitable physical and chemical state for digestion. The pre-treatment of feedstock for AD involves removing non-biodegradable materials that are not suitable for digestion, providing a uniform small particle size feedstock for efficient digestion, protecting the downstream plant from components that may cause physical harm, and removing materials which decrease the quality of the digestate. The stage is housed in a separate building.

Dependent on the waste composition, the non-biodegradable material might include metals, plastics, and glass. These materials can be further separated by using over band magnetic separators and eddy current equipment. Potential revenue can be obtained from the recycled material, however, this will subject to the quality of the same.

Sterilization (optional): In some jurisdictions thermal sterilization (or pasteurization) is required to eliminate pathogens from certain feedstocks. This primarily pertains to Europe where animal byproduct waste must be maintained at 70°C for 60 minutes. Thermophilic temperature ranges within digesters cannot generally be considered sufficient for a reliable sterilization. This process takes place typically in large steel tanks and requires additional heat input, usually utilizing the waste heat from the power generation system through a combined heat and power setup.

Digestion: Waste is retained and mixed in an anaerobic digester to produce gas. Typically the process is carried out in a single vessel; however some technology providers offer multi-stage digestion processes. In the first stage of anaerobic digestion, complex organic materials are broken down into their constituent parts in a process known as hydrolysis. These various digestors are shown in the previous figures. Hydrolysis is immediately followed by the acid-forming phase of acidogenesis, where acidogenic bacteria turn the products of hydrolysis into simple organic compounds. The next stage of acetagenesis occurs through carbohydrate fermentation, through which acetate is the main product, and other metabolic processes. Finally, in methanogenesis or methane fermentation, methanogenic anaerobic bacteria convert the soluble matter into methane.

Post-Digestion: Following digestion, the material leaving the digester is processed to yield usable by-products. In addition to the methane-rich biogas, a major output from the AD process is digestate, the mixture of water and solids remaining after digestion. To recover maximum value from the waste input into the AD system, the digestate should have a useful purpose, and benefit should be derived from its production. The chemical aspects of the digestate quality relates to the presence of:

- Heavy metals and other inorganic contaminants
- Persistent organic contaminants
- Nutrients (phosphorous, potassium, and nitrogen or PKN)

The digestate may have to be dewatered and separated into solid and liquid fractions. The solids can be used directly or composted. The liquid fraction may either be recycled for dilution of fresh waste, applied to land as a liquid fertilizer (frequently under licensing), or sent to a wastewater treatment plant (often following some separation of solids).

These digesters are broadly defined to properly operate within project parameters described in Table 3-1.

Table 3-1. Digester Application Parameters.

Characteristics	**Covered Lagoon**	**Plug Flow**	**Complete Mix**
Digestion Vessel	Deep Lagoon	Rectangular In-Ground Tank	Round/Square In/Above Ground Tank
Level of Technology	Low	Low	Medium
Supplemental Heat	No	Yes	Yes
Total Solids	0.5-3%	11-13%	3-10%
Solids Characteristics	Fine	Course	Course
HRT* (days)	40-60	15+	15+
Farm Type	Diary, Pig	Dairy Only	Diary, Pig
Optimum Location	Temperate and Warm Climates	All Climates	All Climates

Source: AgSTAR Handbook, US EPA AgSTAR Program.
Notes:
*Hydraulic Retention Time (HRT) is the average number of days a volume of liquid influent remains in the digester.

Table 3-2 represents dimensions of major anaerobic digester equipment at facilities processing substrate from approximately 7,000 head of dairy cattle.

Table 3-2. Major Equipment Sizing*.

Parameter	**Total**
Substrate (metric tons per year, wet)	116,000
Buffer tanks	
Number	2
Diameter (m)	16.5
Height (m)	21.2
Anaerobic digestion tanks	
Number	6
Diameter (m)	18.6
Height (m)	21.9
Dewatering feed tank	
Number	1
Diameter (m)	18.5
Height (m)	23.7
Total land area (ha)	5.3

Source: Black & Veatch.

*For a typical facility processing substrate from 7,000 head of adult cattle.

As discussed previously, biogas is composed primarily of methane and carbon dioxide, but can also contain impurities that include foam, sediments, hydrogen sulfide (H_2S), ammonia (NH_3) inert compounds (largely nitrogen) and siloxanes. For digester gas, the gas will also be saturated with moisture at the operating temperature of the digesters. The carbon dioxide present in digester gas, as in LFG, dilutes the energy content of the gas and lowers its calorific value, but often is not removed when used on site for power generation.

Digester gas is typically saturated with moisture at the operating temperature of the digesters, so moisture is removed similar to LFG processes. If not removed, the moisture will condense and accumulate in the lower sections of piping as the gas cools, hindering gas flow. There are similar issues with contaminants and H_2S as with LFG projects.

(a) Digester Gas Power Projects (250 kW – 5 MW)

Biogas produced from digesters can be utilized on-site to produce power or generate process heat. Power can be generated from reciprocating engines, gas turbines, boilers coupled to a steam turbine, or fuel cells. Internal combustion reciprocating engines have been identified for the SER as the preferred technology.

The majority of on-site power generation projects using biogas utilize reciprocating internal combustion engines designed specifically to work on low to medium heat value biogas, reducing the amount of gas treating required. The type and size of reciprocating engines are similar to landfill gas projects, as described previously, though typical projects for farms are on the smaller side. These would be operated in a similar manner as landfill gas ICE projects. Efficiency and load factor for engines will be similar to those described in Section 3.1 (a). As previously discussed, impurities should be removed from the biogas and, if not removed, will reduce the life of the equipment.

3.3 Project Summary

Table 2-3 summarizes the performance and cost characteristics of biogas power generation equipment using either LFG or digester gas inputs.

The emissions associated with combustion of biogas are show in Table 3-4.

Table 3-3. Performance and Cost Characteristics of Biogas (LFG and Digester Gas) Power Generation Equipment.

	Microturbines	Reciprocating Internal Combustion Engines	Simple Cycle Gas Turbines
System Size			
Capacity (kW)	30-250	250-3,000	3000-10,000
Footprint of Landfill Sites (ha)	<10	10-35	>35
Footprint of Anaerobic Digester (ha)	-	5**	-
Performance			
Electrical Efficiency (%)	23-27	30-33	22-30
Overall System Efficiency with Heat Recovery (%)	64-73	74-81	68-71
Capacity Factor	80%-90%	80%-90%	80%-90%
Gas Consumed (m^3/day)	400-3,000	1,000-26,000	30,000-100,000
Water Consumption			
LFG	Negligible	Negligible	Negligible
Anaerobic Digester	?		
Typical Costs			
Capital Costs ($/kW)*	4,000-4,800	1,500-2,500	2,000-2,500
Maintenance Costs ($/MWh)	25-30	16-20	12
Engine/Turbine Replacement Frequency (hours of operation)	20,000	30,000-72,000	25,000-50,000

Source: Black & Veatch and US EPA.
*Does not include cost for collection systems or anaerobic digesters
**Does not include area for raising animals that produce waste

Table 3-4. Emissions Rates from Biogas Combustion.(a)

Pollutant	Simple Cycle Gas Turbines	Reciprocating Internal Combustion Engines (ICE)(b)	Microturbine
NO_x (g/MWh)	490 – 1102	671 – 2,681	227 – 363
CO (g/MWh)	240 – 322	2,409 – 3,751	136 – 662
SO_2	Varies(c)	Varies(c)	None
PM	None(d)	None	None
VOC (g/MWh)	None	838-894	9 – 454
CO_2 (kg/MWh)	640 – 856	529 – 607	774 – 875

Sources: US EPA and California Air Resources Board.
Notes:
(a)Without emissions control equipment.
(b)Lean fuel mix.
(c)Depends on sulfur content of fuel.
(d)Requires treatment of fuel to remove PM.

(a) Interconnection Requirements and Components

The combustion engines and gas turbines are induction generators that require reactive power, depending on the output power and power factor correction, which can cause self-excitation, thus increasing harmonic content. Increasing harmonic content can create stability concerns for an interconnection, especially within weaker power systems (e.g. radial distribution lines). Induction generators also have subtransient reactance inherent to the machine, which contributes to high fault current at lower voltages. Different padmount transformer configurations can also increase or decrease the amount of fault current onto the system, so it is important to design the system to keep the zero sequence impedance to a minimum, but still have a ground reference (so no overvoltage scenarios occur). Series neutral reactors or resistors can be added to the neutral connections of the collection system to increase the zero sequence impedance, thus decreasing the fault current. For additional background on interconnection issues, see Appendix B.

Biogas plants have a distinct operational advantage, as they can be used as a base load plant, since the fuel source can be controlled and scheduled. This allows for load following and the reduction of voltage imbalances to the system which cause stability issues like flicker.

Biogas projects are typically only up to 5 MW in size and can be interconnected at distribution voltages, but should not exceed the maximum load of a substation. It is usually too costly to facilitate an interconnection at a higher voltage; however, there are no technical constraints to doing so. At distribution voltages, it is more reliable to interconnect directly to a substation, not tap a line, due to the fault contribution to the system. Therefore, a new line needs to be added to connect the project to the nearest substation. For all biogas projects, regardless of size, load flow, short circuit, and stability studies should be completed to ensure that there are no unforeseen issues due to the specific interconnection point.

(b) Availability of Components in Ukraine

In order to qualify for the Green Tariff from 2012 onwards, qualifying renewable energy facilities must contain at least 30% of raw materials, supplies, fixed assets, works and services of Ukrainian origin (or “Ukraine content provision”) in the cost of construction. The content requirement increases to 50% by 2014.

Small generator sets are potentially available in the country as they are standard equipment. Collection system is also fairly standard equipment. Anaerobic digestion components may need to be imported or custom built.

3.4 Site Considerations

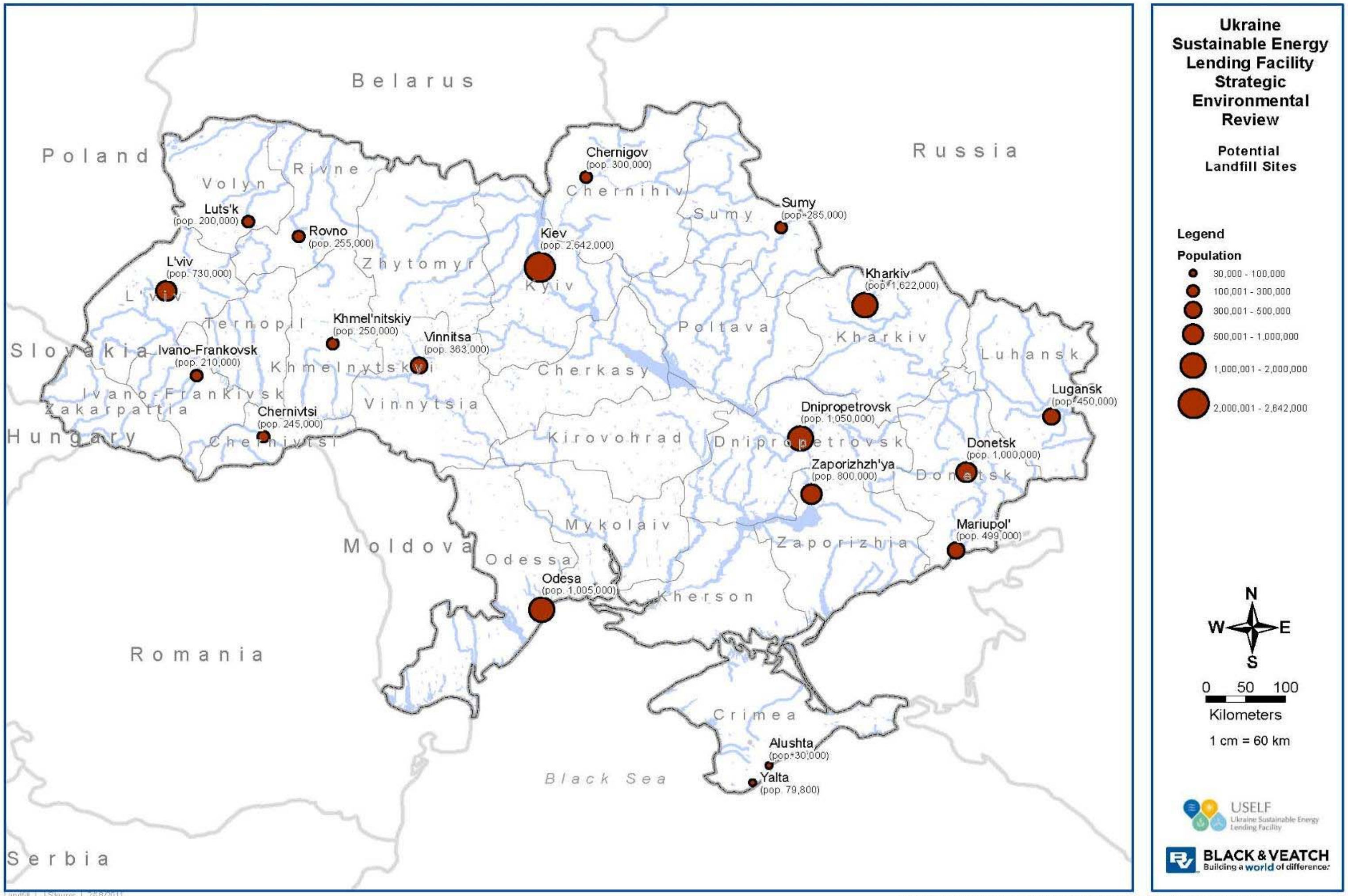
Chief site considerations include the proximity and amount of substrate for the generation of biogas (i.e. size and age of landfill for LFG and number and proximity of livestock for Digester Gas), the amount of space available to construct the required facilities to capturing and cleaning the biogas, access to the facilities, proximity to transmission lines, proximity to load centers, and capacity of existing transmission lines. Other concerns such as visual and odor impacts on local community are not likely a concern for areas that already have landfills and farms.

3.5 Construction Activities

The specific requirements of construction are project specific and dependent on the biogas source (LFG, animal manure and substrate type) and the size of the project. The following discussion is intended to represent typical expected construction activities. Additional activities may also be necessary at very remote locations or for very large facilities; they can include constructing temporary offices, sanitary facilities, or a concrete batching plant

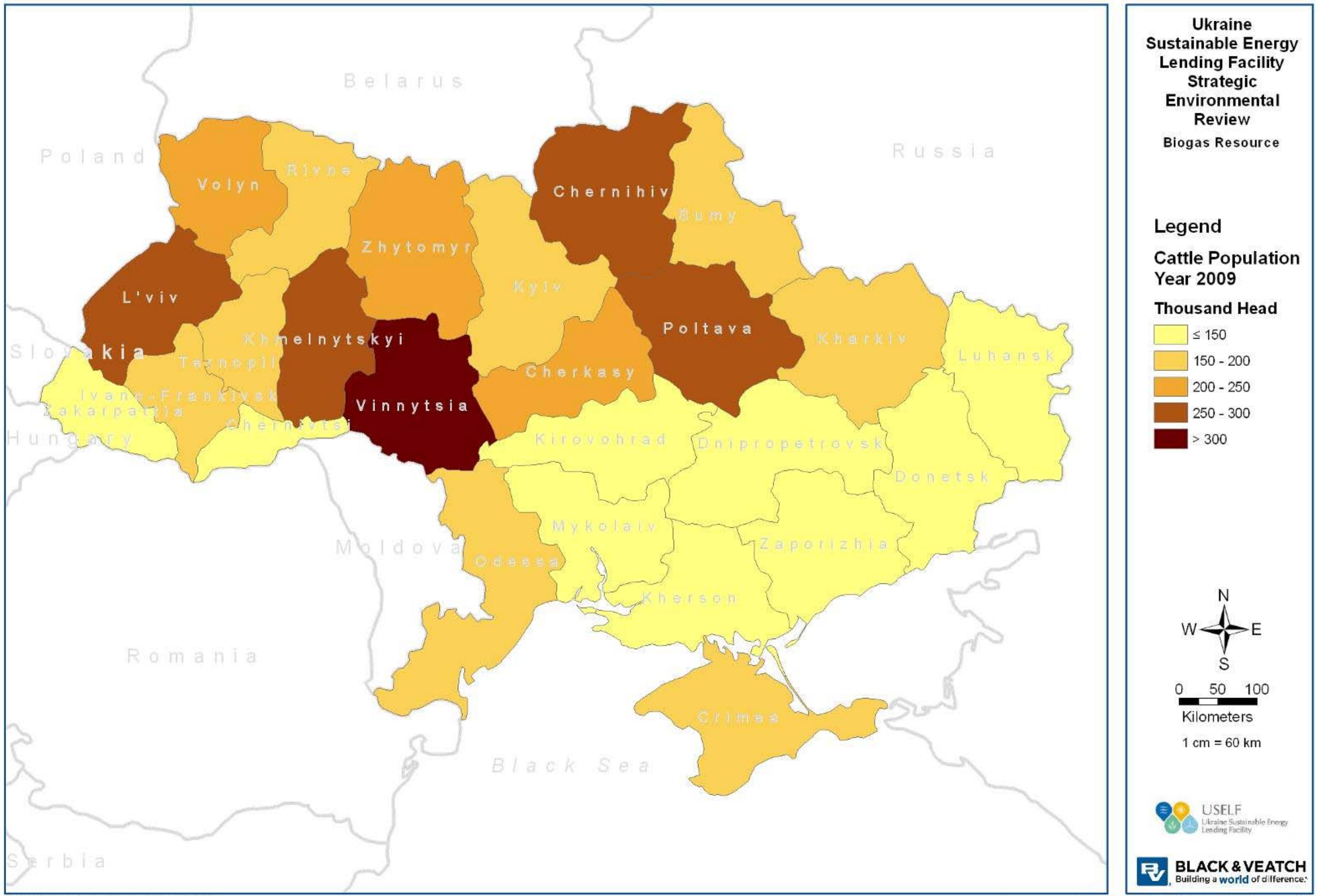
- Construction of access roads, securing site (e.g. fences, gates)
- Clearing and grubbing of the site, removal of vegetation
- Performing site grading and excavation (shallow),
- Construction of underground utilities,(water, drainage)
- Construction of gas collection facilities (LFG)
  - Construction of wells
  - Installation of gas collection system
  - Installation of lining / cover
- Construction of manure/substrate collection system (animal manure)
  - Site specific, dependent on amount and type of substrate and proximity of animals to anaerobic digestion facility
  - May include activities such as installation of trenched piping and pumps
- Erection of steel and reinforced concrete structures,
  - Foundations for gas cleaning equipment, mechanical power generation facilities, AD tanks,
  - Construction of formwork
  - Pouring, compacting concrete, curing and striping of formwork
  - Erection of steel members
- Installation of mechanical equipment
  - Gas cleaning equipment (foam/sediment, CO_2 removal, H_2S removal, dewatering, siloxane removal equipment)
  - Power generation equipment (turbines, ICE, microturbines),
- Startup, testing, and acceptance

FIGURES



Sources: Matveev,Y., 2010; Ukrainetrek.com; DeLorme; ArcWorld Supplement; ESRI.

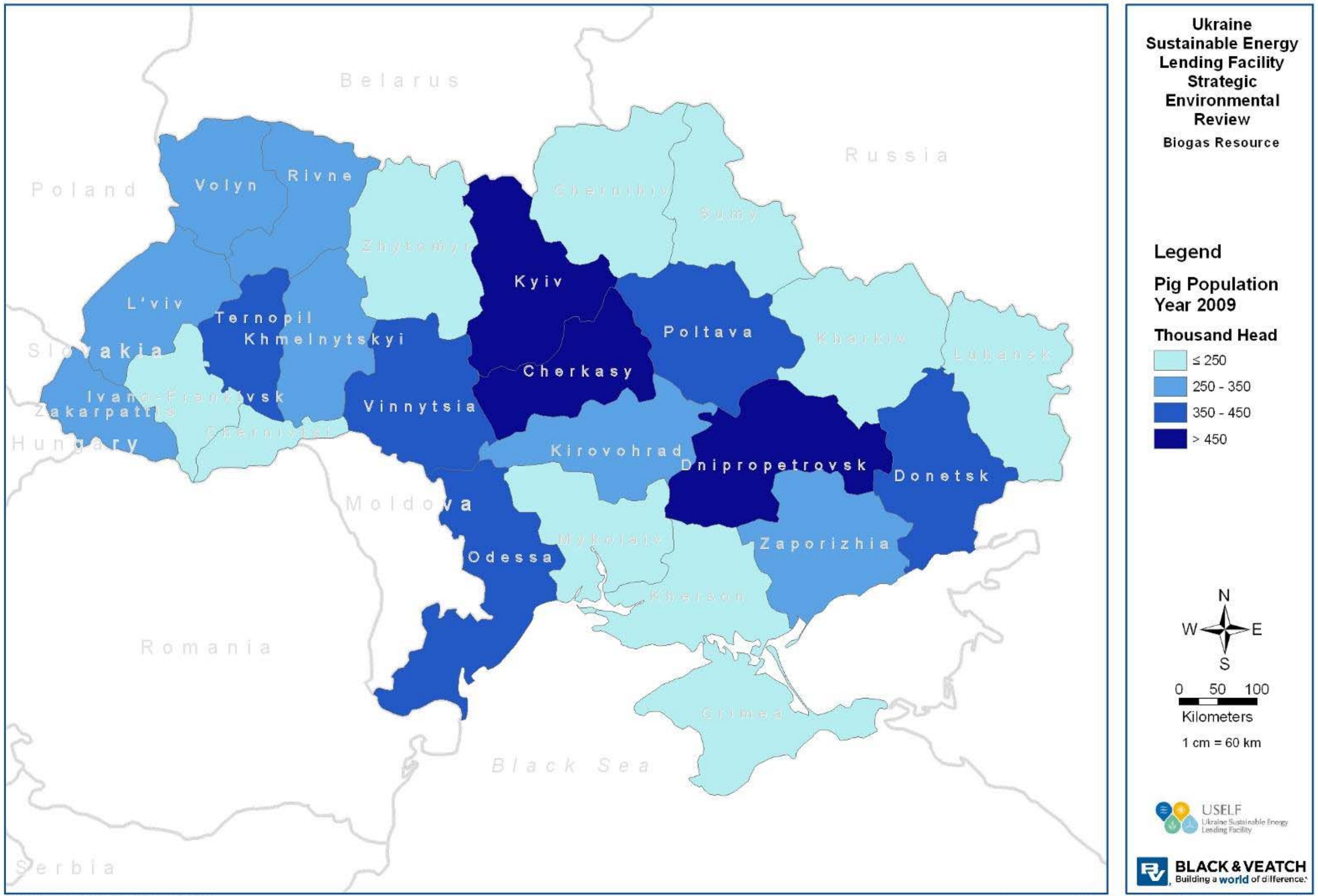
Figure 3-1: Candidate Landfill Sites Under Review



BiomassResource_Cattle vX.mxd | J.Steurer | 5/10/2011

Data source: ESRI; National Statistical Yearbook of Ukraine

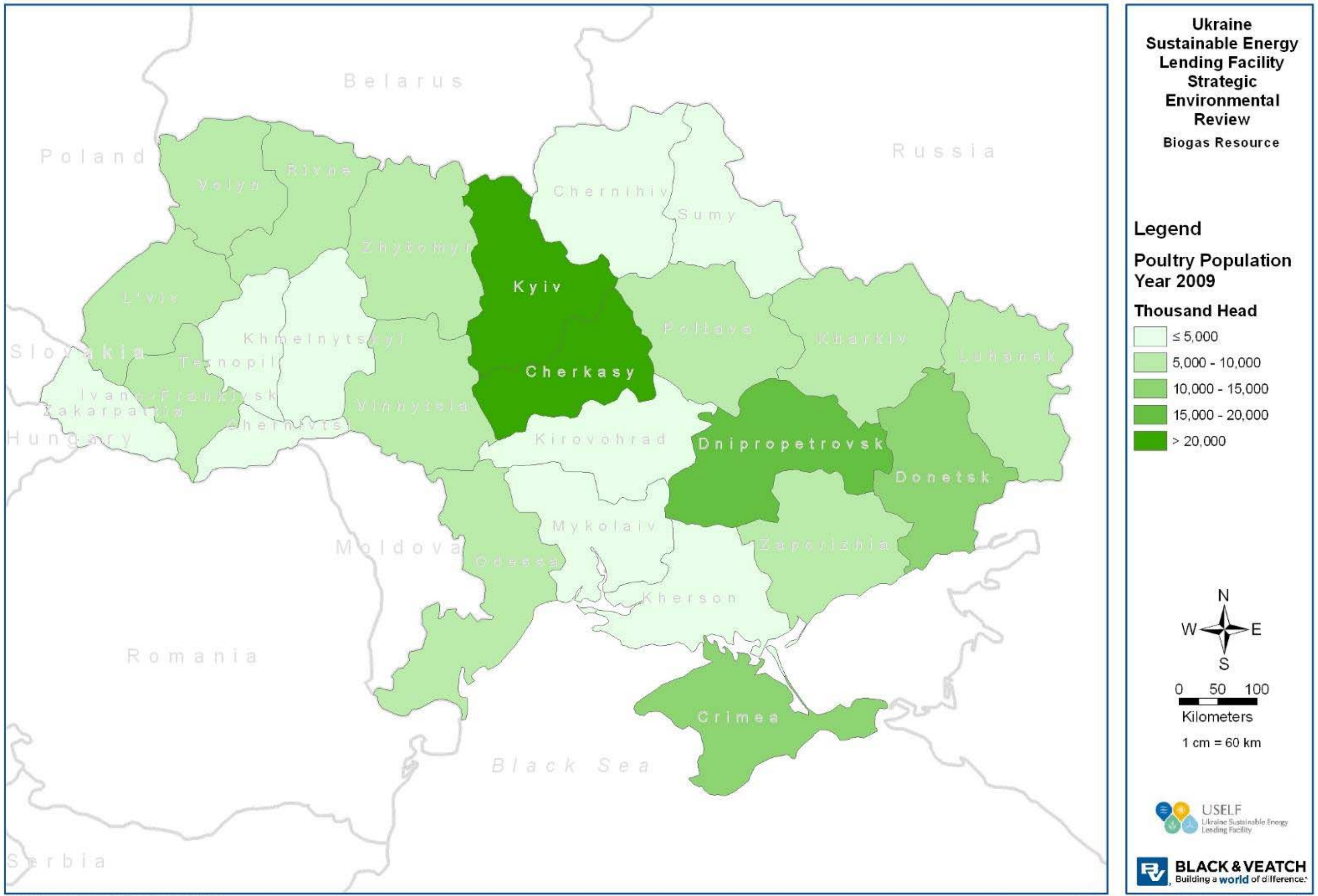
Figure 3-1. Ukraine Cattle Population by Region (2009).



BiomassResource_PigsvX.mxd | J.Steurer | 5/10/2011

Data source: ESRI; National Statistical Yearbook of Ukraine

Figure 3-1. Ukraine Pig Population by Region (2009).



BiomassResource_Poultry vX.mxd | J.Steurer | 5/10/2011

Data source: ESRI; National Statistical Yearbook of Ukraine

Figure 3-1. Ukraine Poultry Population by Region (2009).

APPENDIX A. CANDIDATE LANDFILL SITES

	Town	Population	Year Open	Year Closed or Will Close	MSW (tpa)	MSW in place (M tonnes)	Area (Ha)	Depth (m)	Estimated Capacity (MW)
1	Kiev	2,642,000	1986		500,000	7.5	35.5	15 to 20	5.8
2	Kharkiv	1,622,000	1975		200,000	2.2	20.8	30	1.7
3	Dniproperpovsk	1,050,000	1998		85,000	0.5	7.5	15	0.4
4	Odessa	1,005,000	1972		250,000	5.3	30	22 to 25	4.1
5	Donetsk	1,000,000	1991	2021	150,000	2.5	21.5	10 to 15	1.9
6	Zaporizhzhia	800,000	1952		270,000	8 to 12	47	25	7.8
7	Lviv	730,000	1959	2008	230,000	8.4	33.3	35	6.5
8	Mariupol - Ordzhonikidzevsky	480,000	1976	2008	100,000	2.5	12.3	20	1.9
9	Mariupol		1967	1976		2.142	12.3	25	1.7
10	Luhansk	450,000	1979		80,000	2.5	8.4	20 to 25	1.9
11	Khmelnitsky	250,000	1956	2010	75,000	3	8.8	35	2.3
12	Rivne		1959	1989	120,000	2	22	15 to 25	1.6
13	Chernigov	300,000	1961		110,000 - 180,000	2 to 2.5	14	15 to 20	1.8
14	Lutsk	200,000	1992	2010			8.9	10 to 12	n/a
15	Alushta		1960			0.83		40	0.6
16	Chernihiv		1961			4	24.6	20	3.1
17	Chernivtsi		1995		70,000- 80,000	0.8	25	15 to 18	0.6
19	Ivano-Frankivsk		1992	2012					0.0
20	Sumy Landfill # 1		2007	2013		300,000 m3	7	14	n/a
21	Sumy Landfill # 2		1998	2004			6	10	n/a
22	Sumy Landfill # 3		2002	2007		1.1	6	22	0.9
23	Sumy Landfill # 4		1980	1997		2.4	12	20	1.9
24	Vinnitsa		1985	1994					n/a
25	Yalta		1973	2006	110,000	1.2	4.15		0.9

Assumption: 8.5 cubic meter of LFG is available for utilization for every million tons of WIP and LFG contains 50% methane.