The Economics of Biogas in the Hog Industry

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Abbreviations

ILO - intensive livestock operation

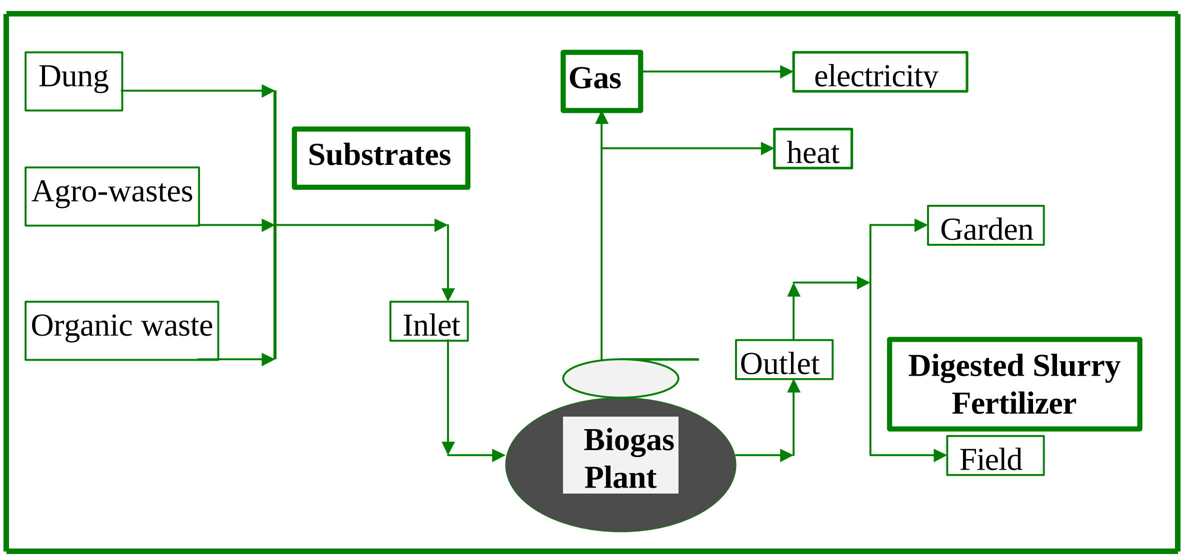
CHP unit - combined heat and power unit

Introduction

Climate change and the need for renewable energy have emerged as two of the most crucial issues that researchers, practitioners and corporations will have to deal with in the next millenium. These two issues have come to a head in Saskatchewan as the structure and practices of the hog industry have been experiencing significant changes. In particular, there has been a shift from small hog operations (20 to 30 sows) to larger and more intensive operations (600 to 1200 sows).[1] Intensive livestock operations have given rise to several environmental issues concerning methane emissions and the disposal or spreading of manure.[2] Public concerns about climate change, air pollution, water quality and rising energy consumption all place pressure on producers and industry to reduce emissions and promote pollution-free sources of energy.[3]

One of the most generally available sources of renewable energy is biogas.[4] Biogas digesters have been used extensively in developing countries as sources of pollution-free heat and electricity, enriched fertilizer, and waste-management, but the success of digesters in colder climates in the past has been mixed. Biogas digesters have been proven to control odour, stabilize waste volatility, and convert methane emissions to usable energy. There is a great potential for efficient energy production for both individual producers and large-scale livestock operations. Not only would biogas digesters provide these operators with a waste-management system and emissions reductions tool, but also a source of pollution-free heat and electricity. The surplus energy produced by biogas digestion could also be sold for public consumption. As the technology involved in biogas digestion has improved since its inception thirty years ago so has the need for such measures. A cost-benefit analysis of the use of methane digesters for hog operations in Saskatchewan will be performed to confirm the positive returns digesters would provide.

Figure 1: Basics of Biogas Digesters



(Sourced from http://gate.gtz.de/biogas/basics/basics.html)

Biogas is released from bacteria through the process of bio-degradation under anaerobic conditions. Methanogens, or methane producing bacteria, generate methane gas through the decomposition of organic materials. Raw material is loaded into the digester where the heat and anerobic environment encourage the growth of methanogens. Inside the digester the material divides into three distinct layers. The heavy raw manure sinks to the bottom, a watery layer containing the liquid effluent and bacteria sits in the middle and a layer of scum forms over the top.[5] Agitation is crucial to prevent the formation of this scum layer because it inhibits fermentation and to avoid differences in temperature within the digester, to mix in fresh materials, and to encourage a uniform bacterial density.[*] Rapid agitation should be avoided as it can lead to the disruption of bacterial communities. Agitation is also necessary to ensure even temperature without "hot spot" within the digester.[6]

Temperature is a very important factor in the success of biogas digesters. The minimum average substrate temperature is between 20 and 28 degrees celsius to be economically feasible.[7] Substrate temperature can be more efficiently maintained if the digester is located close to the source of the raw material and the warmth of the animals bodies is retained.[8] The northern weather conditions of Saskatchewan including winter temperatures of -20 - -40 degrees celsius would require all piping to be insulated and a heat exchange system for the digester. A biogas hot water boiler is an effective means of maintaining the digester's ambient temperature requirements through a coil heat exchanger. Heated water can be pumped through pipes within the digester, at the most 20% of the biogas will be expended to maintain the required reactor temperature. This loss can be combatted by the saving accrued through building a smaller digestion tank.[9] Through this system it is possible to maintain a stable temperature with a variance of only 2-8 degrees celsius in a northern climate.[10]

The biogas which is released through anaerobic digestion is a mixture of the following gases: methane (Ch_4) at 40-70 volume %; carbon dioxide (CO_2) at 30-60 volume %; and 1 -5 volume % of other gases such as hydrogen (H_2) and hydrgen sulfide (H_2S). Biogas is a natural source of renewable energy which is pollution-free.[11]

The quantity of gas produced is directly related to the type of raw material the digester is fed. Table 1 compares the suitability of different materials for digestion. and Table 2 shows the productivity of raw swine materials.

[*] .Some of the more advanced plug and flow systems do not require agitation.

Table 1: Expected Yields of Various Biomass Materials

Biogas yield to expect	Yield	Case		
	Nm^3/m^3	1	2	3
Cattle manure [m^3/day]	27	50	50	50
Fish waste [m^3/day]	185	0	2.5	2.5
Fat waste [m^3/day]	700	0	0	2.5
Biogas Production		1350	1810	3560
Size of CHP unit [kWh]	El	112	150	296
continuos operation	Heat	196	263	517
size of burner	Heat	308	413	813
yearly production from CHP unite	El	730.000	980.000	1.920.00
[kWh] 6500 hours	Heat	1.270.000	1.710.000	3.360.000
Yearly production from burner 1500h [kWh]	Heat	460.000	620.000	1.220.000

(sourced from http://www.folkcenter.dk/rokai/rokai.html)

Table 2: Unofficial values of biogas yield from swine wastes, July 1998

Branch	Waste Type	VS [%]	CH_4 production per VS [Nm^3/kg]	Biogas production per ton biomass [Nm^3/ton
Agriculture	Porkers	5.8	0.29	24
	One year sows	6.4	0.29	28
Pig slaughterhouse	Content of stomach/gut	16	0.40	96
	Fat and flotation slurry	36	0.58	313
	Remains after sieving	12	0.30	54

(sourced from http://www.folkcenter.dk)

Hog manure is a good raw material for anaerobic digestion because of its relatively uniform physical and chemical properties.[12] A medium adult pig produces approximately 2 kg of recoverable manure per day. This represents approximately 60 *l* of biogas, which is 60% methane, that would be produced from a semirustic, or technologically-poor, plant.[13] Table 3 shows the gas production potential of a one hundred and fifty pound hog at a more technologically advanced plant while table four illustrates the manure production of pigs at various life stages. This data can be used to estimate the total manure and potential biogas production from a hog operation which has hogs at various levels of development.[†]

Table 3: Potential Gas Production Of Swine

	SWINE 150lbs
gas yield cu. ft. per lb volatile solids destroyed	12
volatile solids voided lb/day	0.7
percent reduction of volatile solids	49
potential gas production cu. ft. per day	4.1
energy production rate. BTU/hr/animal	103
available energy BTU/hr [after heating digester]	70

(sourced from Fulhage, Sievers, and Fischer, p.2)

Table 4: Manure production from individual hogs

Weight (kg)	**Age** (weeks)	**Manure production** (litres/day)
4-11	3-6	1.1
23-34	9-12	3.4
18-91	8-22	5.1
80-91	20-22	9.1
Nursing sow and litter	(wean at 3 weeks)	15.6
Nursing sow and litter	(wean at 6 weeks)	19.5

(sourced from Agriculture Canada, *Farm Buildings Handbook)*

[†] When calculating biomass availability seasonal variations in individual hog weight and herd numbers must be taken into consideration (http://www.greentie.org/class/ixh0705.htm)

Biogas potential can also be calculated according to amount of raw manure. Approximately 1 kg pig dung is equivalent to 60 litres of biogas or 30 litres of biogas per day per kg weight.[14]

Table 5 compares the manure and gas production potential of cattle, hogs and poultry for the purposes of digestion.

Table 5: Manure and Biogas Produced by One Animal

Animal	Manure produced by one animal (ft^3/day)	Additional water % of manure	Biogas produced ft^3/day
Cow	1.5	25	50
Pig	0.2	200	7.8
Chicken	0.004	800	0.4

(sourced from Hazeltine and Bull, 1999, p.150)

Costs and Benefits of Methane Digestion Systems

When considering the feasibility of biogas plants for the hog industry in Saskatchewan many economic and non-economic factors must be considered. These include the monetary costs of a methane digester and the monetary and non-monetary benefits of digesters. These issues will be treated in the following section.

Costs

The costs of establishing and running a methane digester are dependent on the specific type and size of the digester. Hog manure has an optimal retention time of 15-25 days to maintain fermentation bacteria at an adequate level.[15] The capacity required of a hog operation digester, therefore, is approximately 15 times the daily volume of manure.[16] The average daily amount of manure produced by different animals at different life stages has been shown in Tables 3, 4 and 5. The size of the digester will be determined by these numbers. A few common costs can, however, be applied to all biogas operations. These costs are capital costs and operational costs.

Capital Cost

Capital costs of establishing a biogas plant include interest and financing of the plant, interest rate, loans, equity, etc[17] and is dependent on the size of the operation. A rough estimate of the cost of establishing an unheated biogas digester, not including the purchase or opportunity costs of land, is approximately 50-75 U.S. dollars per m^3 capacity.[18] To reduce capital costs digesters may be built with local construction materials to local specifications.[19] Table 6 show a capital cost analysis in US dollars for biogas digester facilities at hog operations of three hundred, one thousand, two thousand, three thousand, and five thousand pigs.

Table 6: Capital cost estimation (US$) of treatment units for pig farms with sizes 300, 1000, 2000, 3000 and 5000 pigs

Equipment items	Farm size (number of pigs)				
	300	1000	2000	3000	5000
Solid/liquid separation unit	5340	11949	19037	24932	35017
Anaerobic reactors	12467	27417	43506	56968	80205
Aeration tank	3545	8072	13049	17063	23882
Polishing tank	2800	6376	10306	13476	18862
Sludge dewatering bed	2600	5460	8320	11440	16640
Total equipment cost	26752	59274	94218	123879	174606
Tax(4%)	1070	2371	3769	4955	6984
Total capital cost	27822	61645	97987	128834	181590

(sourced from Yang and Gan, 1998, p.25)

Operational Cost

Acquisition of raw materials, water for mixing materials, feeding and operations of the plant, preventative and on-going maintenance, supervision, storage and disposal of the slurry, gas distribution and ultilisation, and administration are all different operating costs associated with running a biogas plant.[20] Table 7 shows the running costs, in US dollars, for biogas plants for farms of various sizes.

Table 7: Operation and management cost for swine waste treatment system (US$/year)

	Farm size (number of pigs)				
	300	**1000**	**2000**	**3000**	**5000**
electricity	1900	6336	12672	19008	31680
labour	2400	3000	4200	5400	7200
contingency	426	934	1688	2441	3888
grand total	4726	10270	18560	26849	42768

(sourced from Yang and Gan, 1998, p.26)

As the training of personnel can have a difference of a factor of three on the gas yields in biogas plants management by a skilled person is necessary for an efficient and profitable biogas plant.[21] Without proper management and the willingness to train personnel the potential efficiency of a digester is questionable.

Digester personnel must monitor the pH levels in the digester as the pH value must be alkaline to avoid killing the methanogenic bacteria. A pH balance stabilized between 7 and 8.5 is ideal. If the balance drops below 6.2 the acid concentration will become toxic to the bacteria thereby limiting or ending the bio-degrading process.[22]
Using urine, instead of water, is preferable to dilute the solid substrate to help maintain the pH balance.[23] Digester personnel must also test for the presence of heavy metals, antibiotics, or detergent can also inhibit the fermentation process.[24] The handling of these and other maintenance issues can make the difference between efficient and an inefficient digester

Table 8 shows cost estimations for digester plants, in Hawaii, in US dollars for farms of varying sizes. This estimation includes some benefits such as gas and fertilizer production, but excludes others such as irrigation effluent. The cost of the plant is considered on a per animal basis and the break even point is shown to be at 830 pigs. Capital costs can be reduced for small operations through new technologies, such as the use of high density polyethylene in place of current tank materials. The use of these technologies lowers the break-even point from 830 pigs (average weight of 77kg) to 227 pigs.[25]

Table 8: Total cost estimation of treatment system in US$

Annual operation balance	Farm size (number of pigs)				
	300	**1000**	**2000**	**3000**	**5000**
Gas production	2068	6893	13786	20679	34350
Fertilizer value of sludge (value of irrigation effluent not included)	3823	12744	25488	38232	63720
Operation and management cost	-4726	-10270	-18560	-26849	-42768
Balance	1165	9367	20714	32062	55302
Loan					
Initial capital cost	-27822	-61645	-97987	-128834	-181590
Operation period (years)	10	10	10	10	10
Annual interest (%)	6	6	6	6	6
NPW of total cost	-19248	-7296	-54468	-107142	-225433
Unit cost ($/pig/year)	-6.42	0.73	2.72	3.57	4.51

(sourced from Yang and Gan, 1998, p.26)

The total costs of establishing and maintaining a biogas digester may be calculated through the Annuities Method - a comparison of net payments and net benefits over a one year period.

$$AN = B-C-l0CR(i,T)$$

If AN if positive the operation is regarded as profitable in absolute terms

where B is equal to the annual benefits

where C is equal to the annual costs

where l0 is equal to the total investment capital, initial investment plus reinvestments over time

where CR is equal to the cost of financing the operation

or CR (i,t) = (qt(q-1)/(qt-1+((1+I)ti/((1+I)t-1)

where i is assumed interest rate in percent

where q is 1+i

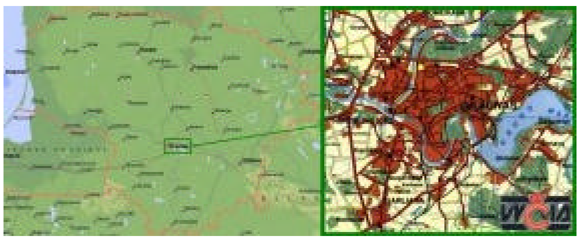
where t is time in years[26]

Much of the concern in attempting to run biogas digester projects in North America has been surrounding the issue of energy efficiency. Can the digester produce more energy than is required to maintain its ambient temperature through a cold northern winter. Through the advances in materials, construction, and management digesters are not just for tropical climates anymore. Proof of the suitability of digesters for northern environments can be found in the Rokai Pig Farm Demonstration Biogas Plant in Kaunas, Lithuania.

Rokai Pig Farm Demonstration Biogas Plant

This project was initiated by the Danish Folkecenter for Renewable Energy, and has been financially supported with 88% from the Danish Environmental Protection Ministry. The remaining 12% has been financed by the AB VYCIA Farming Company, where the biogas plant is installed and operated. The project is intended as a pilot demonstration, technology transfer, and education plant for Lithuania and the surrounding Baltic countries.

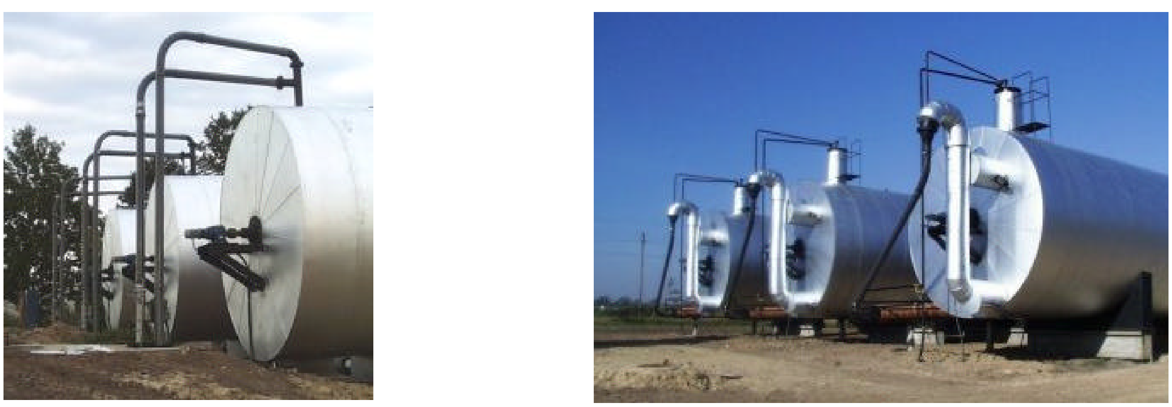
Figure 2: Vycia Farm Location in Kaunas, Lithuania



Technology

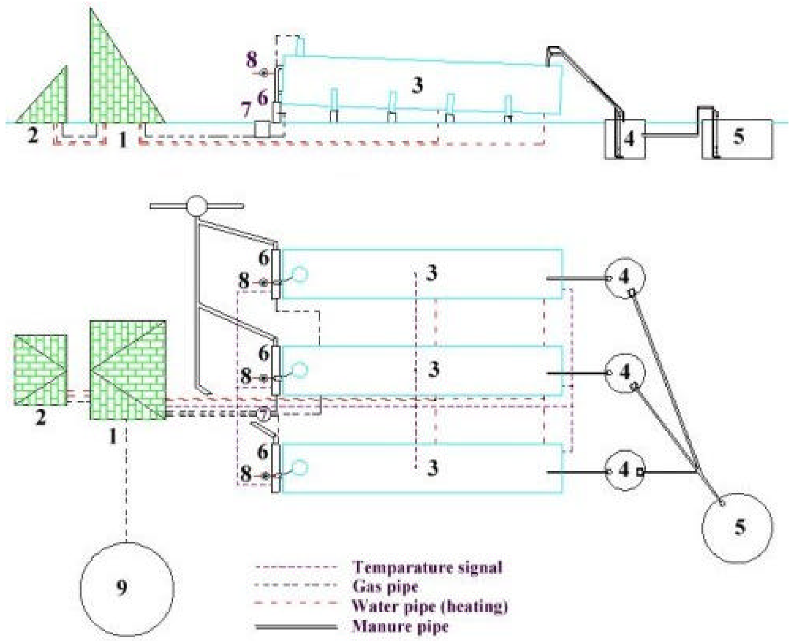
The Biogas Plant is scaled to the amount of resource available on the VYCIA farm. The daily 60 m^3 of manure from the 11.000 pigs, is by the anaerobic digestion converted into a "more ready to use" fertiliser. The produced biogas is by co-generation converted into electricity and heat, which will reduce the farms expenses for energy significantly. The technology gives possibility for much higher production with surplus of electric energy, which will be sold to the public grid. The following figures show the layout and schematics of the Rokai plant.

Figure 3: Rokai Digester Plant



left picture Manure inlet, mixer tanks, agitator motors/gears. ***right picture*** Manure outlet, gas outlet.

Figure 4: Schematic drawing of the biogas plant



1) Technical building, control room, show room, laboratory, boilers.
2) Technical building, co-generation. 3) Digesters. 4) 30m^3 mixing tank. 5) 60m^3 pretank.
6) Sulphur cleaning system. 7) Condensate separation. 8) Air pump. 9) Gas holder.

Operation

Each 300 m^3 digester receives daily 20m^3 manure in the 30m^3 individual mixing tanks. Waste additives are added and mixed in the same tank. The manure is pumped into the digester in intervals every 2 hours over a 24 hour period. An equivalent volume of manure is displaced at the outlet end of the digester. The process is heated to a temperature between 35 °C and 50 °C. Heating is obtained by integrated heat exchanger, and heat loses are minimized by a 200 mm insulation covered by weather proof steel plate coating. To keep the manure homogeneous and to avoid scum layer, the manure is mixed at intervals by a slowly rotating axial agitating system. The agitator also transports the sediments to the sand outlet, where it can be removed. The biogas leaves from the top of the digester at a low pressure, sufficient to overcome the losses in pipes and the counter pressure from the floating gas holder. The gas holder delivers pressure enough to operate gas burner and co-generation motor without any compressor to raise pressure. If the system pressure exceeds 45 mbar, the gas is released from the digester by a siphon trap.

The following Tables give the technical, production, consumption, and economic data for the Rokai plant.

Table 9 :Technical data for Rokai Digester Plant

Manure	: 60 m^3 pig manure / day
Waste, concentrated	: ~ 3 t / day (depending on availability)
Digester	: 3 x 300m^3 horizontal steel digesters
Gas production	: 1200 - 3600 m^3/day
System pressure	: 25 mbar , (max. 45 mbar by safety siphon trap)
Gas storage	: 60m^3
Co-generation	: 1 x 75 kW and 1 x 110 kW
Boiler/burner	: 1 x 300 kW gas burner and 1 x 300 kW oil/gas burner
Sulphur cleaning	: Aerobic external biological process
Control system	: PC based control- and data acquisition system (developed by Folkecenter).

Table 10: Production data for Rokai Digester Plant

Biogas production	: 1200 m^3/day 1)
Electric production	: 2400 kWh_{el}/day
Electric production	: 700.000 kWh_{el}/year 2)
Heat production	: 4200 kWh_{heat}/day
Heat production	: 1.600.000 kWh_{heat}/year 3)

1) from manure only. By adding concentrated waste, the technology gives possibility for gas production of 3600 m^3/day.
2) by 80% duty time of co-generation.
3) by 80% duty time of co-generation and boilers 80% duty time of remaining 20%.
Maximum 25% is used for process heat. There will be surplus of heat during summer.

Table 11: Rokai Farm Energy Consumption

Electricity	: 3.700.000 kWh_{el} /year *

* 2.300.000 kWh is used for heating. Will be replaced by heat and electricity from biogas

Table 12: Key economical figures *

Support from Danish Environmental Protection Ministry (88%)	3.900.000 DKK
Financing from AB VYCIA FARMING COMPANY (12%)	540.000 DKK
Total	**4.440.000** DKK

(* exchange ratio : 1 USD ~ 6,50 DKK , 1 DEM ~ 3,85 DKK)

The Rokai plant is an excellent example of an efficient cold climate plant.

Benefits

The benefits accrued from establishing and running a biogas digester for a hog operation fall into two basic categories: monetary and environmental. Each will be discussed with reference to hog operations in Saskatchewan and the potential of interaction between monetary considerations and environmental concerns in the future.

Monetary

Economic gains that can be made from operating a biogas plant on an ILO are many. Those which will be discussed here include the production, consumption and sale of energy and the production, use and sale of fertilizer and feed.

Economic benefits of the production, use and sale of energy

Through the use of co-generation heat and power units, or CHP units, biogas can be converted to electricity and heat.[27] Electricity can also be produced using a generator engine which runs on biogas. No purification is necessary and a biogas pipe from the digester may be connected directly to the engine or CHP unit.[28] Biogas can also be burnt without further purification in conventional gas appliances if the gas jets are enlarged to allow for complete combustion as it requires less air to combust than butane or propane.[29] Biogas can be purified if desired by pumping it through an ammonium hydroxide solution which removes the carbon dioxide. As hydrogen sulfide is very corrosive, managers may desire to install a H_2S trap in the gas line to further process the biogas.[30]

Biogas can be used to reduce the consumption of natural gas, coal, propane, or power from commercial sources thereby reducing the running costs of the operation.[31] Household appliances and farm machinery can also be run off of biogas fuel.[32] If the plant is producing more energy than required by the operation the biogas can be stored in a gas bag or compressed and stored in propane tanks until required.[33] Surplus energy produced by running an electric generator or CHP unit can also be sold to the public power grid thereby increasing the profitability of the operation.[34] SaskPower policies allow for sales to the public grid if the operator has the connections and meters installed. SaskPower pays 1.85¢/kW· h for small producers. Bulk sales, such as could be achieved by connecting several ILO's, are handled on a case by case basis.[‡]

If a CHP unit is run efficiently it can produce $2kWH_{el}$ and $3.5kWH_{heat}$ from $1m^3$ of biogas. From a gas burner and boiler, such is used in digester heating systems, $1m^3$ of biogas can produce $5.5kWh_{heat}$. If the burner is both oil and gas then fuel oil can be used in times of biogas shortage, plant adjustment and maintenance, and to provide process heat for a "cold start" of the digester.[35] 88% efficiency can be reached if biogas is utilized in a heat-power combination in generators, engines, or gas appliances.[36] Waste heat from an electrical generator can be recycled into the digester to ensure constant ambient temperature without adding energy to the process.[37]

[‡] electronic communication with SaskPower

Economic benefits of the production, use and sale of fertilizer/feed

A byproduct of the anaerobic process which occurs in methane digestion is the conversion of raw manure to enriched fertilizer. The digester effluent has more available nutrients than raw manure.[38] It is free of disease, germs, weeds, seeds and no longer a threat to water contamination.[39] Through the digestion process organic nitrogen is mineralized and odour production is minimized.[40] It is easy to handle, protects against insects, fungi, bacterial diseases, and soil erosion. The effluent can be used on vegetables and trees as well as agricultural crops.[41] It can improve soil quality, but producers must be careful of soil alkalinization which can occur if too much fertilizer is applied to the wrong type of soil.[42] Slurry is more environmentally friendly and less costly than chemical fertilizers.

Liquid slurry can be used as irrigation fluid instead of water or chemical fertilizer.[43] Hog operations are heavy water consumers with much of the excess water excreted as urine. This consumption results in wastage (another water use concern) and likely increases the costs of manure slurry storage and spreading. A biogas digester would make use of the waste water in the process and make it available for irrigation thereby reducing water consumption, water costs, and chemical fertilizer costs. Post-digestion pig manure slurry or sludge contains nutrients essential for plant growth as well as being relatively free of odor and pathogens.[44]

The nutrients considered essential for agricultural crop growth are carbon, hydrogen and oxygen. The major elements deficient in many soils are nitrogen (N), phosphorus (P), potassium (K), and sulfur (S). The requirement for nitrogen is greater than for other major elements. The major elements deficient in some soils are calcium (C) and magnesium (Mg). The trace elements considered essential for plant growth are sodium (Na), cobalt (Co), vanadium (V) and silcon (Si). The trace elements or micro-nutrients which are found deficient in a few soils are boron (B), manganese (Mn), copper (Cu), iron (Fe), zinc (An), molybdenium (Mo), and chlorine (Cl). In Saskatchewan, nitrogen and phosphorus are generally deficient, while potassium and sulfur may be deficient in coarse Black, Gray-Black, and Gray soils. In Saskatchewan several micro-nureient deficiencies have been found in different areas including but not limited to: maganese, copper, zinc, boron iron, and chloride. These also vary by production system and crop variety.[45] Table 9 shows the results form two studies of the composition of post-digestion effluent.

Table 13: Characteristics of stabilized sludge (based on dry matter)

	Yang and Gan study (1998)	Kuroshima study (1994)

Ash %	26.6	29.4
Org. C %	27.83	N/A
N %	4.54	4.42
P %	3.13	2.76
K %	0.31	0.48
Ca %	8.25	4.70
Na %	0.13	0.48
Mg %	0.97	N/A
Fe ppm	8252	4920
Mn ppm	1374	683
Zn ppm	135	789
Cu ppm	159	164
pH	6-8	N/A

N/A: data not available (sourced from Yang and Gan, 1998, p.25)

As Table 9 shows digester sludge has many of the nutrients which are very important to plant growth and soil health such as organic carbon and readily available nitrogen making it an excellent fertilizer.

Dried digester slurry can also be used as animal feed supplements and fish feed. When used in aquaculture digester slurry stops water degradation which prevents fatal anoxia, or suffocation, in fish stocks.[46]

Environmental

The environmental benefits of biogas

Emissions considerations

Ninety percent of the methane emitted world wide is from the decomposition of biomass.[47] Biogas digesters may reduce methane emissions up to 70% with longer reductions possible at longer retention times. The use of biogas has no air pollutant externalities and may reduce the use of other fuels like coal which emit particulates like Nox and Sox.[48]

Agricultural soils are a major source of both emissions of Greenhouse gases and sinks for Greenhouse gases.[49] Nitrous oxide emissions reduction of approximately 20% from agricultural soils globally could be achieved through the use of biogas digesters. The use of digseter slurry can prevent soil erosion thereby increasing carbon availability and as the nutrients, like nitrogen, are more mobile in digester slurry more are incorporated into the soil.[50] These figures would be even higher in developed nations, like the United States, who have highly managed systems of agricultural production.[51] Efficient reductions of nitrogen emissions[52] have been achieved on fields that are highly fertilized with digester sludge. These fields have been found to have nitrogen oxide emissions levels on par with urban areas reflecting a significant reduction in emissions through the more efficient use of fertilizer and manure.[53]

As soil erosion is decreased with the use of digester slurry fertilizer more organic soil carbon in maintained. This reduces carbon emissions and improves soil fertility as carbon is an essential element for plant growth.[54]

Legal considerations

The main legal environmental issues surrounding intensive hog operations are odour and water pollution. Intensive hog operations produce large amounts of manure. Improper manure storage and management can lead to excessive odour and groundwater and surface water contamination.[55]

Water contamination can occur from surface runoff and underground seepage. Surface runoff places surface waters at risk. Shallow aquifers are particularly susceptible to contamination from leaching occurring from manure spreading (non-point source contamination) and leaching or seepage from manure lagoons (point source contamination). Aquifer contamination can result from manure storage lagoons from seepage or overloading.[56] Feedlots and spills are also of concern with respect to intensive hog operations. Shallow aquifers are commonplace in southern Saskatchewan, and are often utilized for supplying water to farms and rural communities.[57] Regina is of particular concern due to the type of aquifer that supplies a significant percentage (30%) of the city's water. Other areas of Saskatchewan that may be at risk include Yorkton and North Battleford, both of which rely on shallow wells for municipal water supplies.[58]

Saskatchewan, like other provinces, has enacted legislation to deal with the competing interests of the public, the environment, and the agricultural sector. Some statutes, such as *The Environmental Management Protection Act* (EMPA), make it an offence to pollute; although, farmers have enjoyed protection from this type of liability in the past. However, *The Agricultural Operations Act* (AOA) directly concerns farmers, including intensive hog operators. The AOA is referred to as "right to farm" legislation, but can also force the operators of certain size hog farms to adhere to specific agricultural practices and environmental standards. More strict regulations have been put in place by other provinces however which place the "balance" of interests with weight towards the public good. Manitoba has enacted the Livestock Waste Regulation[§] and Quebec has strict manure management requirements under provincial law[**].[59]

Prior to the development of statutory environmental law, environmental liability was generally provided by the common law. If the activities of a farmer or hog operator adversely affect another person, the operator could be liable under a common law action in nuisance, negligence, or the rule in *Rylands v. Fletcher*. However, because common law has been slow to address the changing intensity and complexity of agriculture and there is greater public awareness of the environmental risks of farming the provincial government has enactment environmental statutes to provide a mechanism to close the gap. Thus, there is a mixture of common law and statute law setting the rules for environmental liability in Saskatchewan.[60]

[§] LRW, 1994; revised in 1998

[**] MEF, 1997

Nuisance

Nuisance is a cause of action that is based on an individual's right or interest the use and enjoyment of his or her land.[61] Nuisance occurs when an inconvenience materially or unreasonably interferes with the use or enjoyment of another's land in light of all circumstances.[62]

Nuisance claims can be private or public. A private nuisance claim arises when a person sues another person, typically a neighbour. Remedies for private nuisance actions include abatement,[††] injunctions[‡‡] and damages.[§§] When a person's activity affects the rights of many landowners in a community, the government can bring a public nuisance action. In a successful action, the offending landowner would be ordered to stop the activity causing the public nuisance.

Nuisance Actions related to Hog Operations and Water Pollution

Many nuisance actions have been brought against hog operations. For example, in *Sullivan v. Desrosiers*,[63] offensive odour from a piggery has been held a nuisance. However, in *MacGregor v. Penner*,[64] odour emanating from a hog waste lagoon was found not actionable in nuisance, as the interference was found to be not unreasonable. Although odour emanating from manure is not the same as the contamination of water through improper manure storage or management, the basis for the *MacGregor* decision can provide some insight into what considerations will be made by a court surrounding a nuisance action brought against an intensive hog operation. In considering the *MacGregor* case, Dureault J. explained that the defendant's actions and operation were reasonable and non-actionable considering the nature of the activity, the area (a rural municipality zoned for agriculture), and the condition of the defendant's farm. Consideration was also given to the seasonal nature of emanating odour. Although odour was not considered an actionable nuisance in this case new research has indicated that significant psychological stresses can be associated with odour and this information may affect future suits especially if, as Table 10 shows that complaints are increasing with traditional methods of disposal.[65]

Table 14: Relative contribution of the three major sources for odour emission in other regions of the world

[††] Abatement is possible when there is an urgent need to put a stop to the interfering activity; however, courts have only permitted abatement in emergency situations. See A.M. Linden, *Canadian Tort Law*, 5th ed. (Toronto: Butterworths, 1993) at 533.

[‡‡] An injunction may be granted to prevent the defendant from continuing an interfering activity. Courts in nuisance cases are guided by the same principles of the ordinary granting of injunctions.

[§§] Damages can be awarded in addition to an injunction or in lieu of an injunction when it is oppressive to a defendant or where money is adequate to compensate the plaintiff.

Type of concern	Relative contribution (%) of the source of concern				Survey years	Reference
	Livestock housing	Manure storage	Manure spreading			
Total N Losses	46	16	38	Denmark	late>80s	Rom (1993)
NH_3 emissions	41	14	44	United Kingdom	late>80s	Van der Werden (1995)
Nuisance complaints	34	21	44	United Kingdom	>87=90	MAFF (1992)
Nuisance complaints	31	17	52	United Kingdom	>82	Bondy (1995)
Nuisance complaints	10	20	70	Quebec	>95+96	Marquis and Marshall (1997)

(sourced from: http://www.gov.mb.ca/agriculture/livestock/pork.swine/bab10s08.html)

In comparison to odour, the contamination of water from improper manure management may be substantially more difficult to defend against in a nuisance claim. In *Breau v. Soucy*,[66] a court allowed a nuisance action against a large-scale hog operation, issued a permanent injunction and awarded damages. The hog operator was found liable for allowing liquid manure to seep into a lake from a manure retention pond. As a result of the seepage, the lake was unsuitable for bathing. Among other things, the injunction prevented the hog operator from using the manure retention pond unless it was made watertight and prohibited the discarding of hog waste where it would end up in the lake. The fact that the operator had followed government construction guidelines did not give the operator the right to pollute the region.

Leachate originating from a manure retention pond is an example of point source contamination which has been an actionable claim. In *Portage La Prairie v. BC Pea Growers Ltd.*, where seepage from a sewage lagoon constituted a nuisance because the lagoon failed at its primary and preeminent purpose, to contain the manure.[67]

Negligence

Every farmer has a duty under the common law to conduct farming activities in such a way so as to not harm others. When the activity places others at risk, the farmer may be liable for injuries to others if the farmer's conduct is found to be negligent.

Negligence Actions related to Hog Operations and Water Pollution

In *Melito et al. v. Lenbro Holdings Ltd.*,[68] an action in negligence was successful where the defendant applied a weed killer that mixed with surface run-off water and entered the plaintiff's property along the contours of the land. The weed killer also spread through the air and damaged the plaintiff's garden and trees. The court held that the defendant had a duty to ensure that a licensed operator applied the weed killer and to ensure that run-off contaminated with the weed killer would not enter the plaintiff's land.

Manure, or components thereof, also have the potential to mix with surface run-off water and enter a neighbour's property. However, generally speaking, manure contaminated run-off water would likely not be so concentrated with "manure" so as to cause significant, immediate damages in comparison to weed killer. In this respect, manure may not be as detrimental to property as weed killer, and likely would not attract the same high standard of care as weed killer. Although, if nitrates or faecal coliforms in the manure contaminated run-off were able to enter a water source used for drinking, then there could be significant and immediate damages.

The court in *Melito* also held that there was a duty to ensure that a licensed operator applied the weed killer (likely a statutory duty). For manure to be treated by a court with the same high standard of care as in *Melito* for weed killer there will likely need to be legislation in place that requires a qualified manure applicator for the jurisdiction in question. In this case it would become the farmer's responsibility to assume the additional costs of hiring qualified personnel to handle their manure handling system.

The *Rylands v. Fletcher* Rule: Strict Liability

Strict liability is liability without fault. It is a variation on trespass and negligence which establishes a heavier legal burden for individuals that use their land in a non-natural way that endangers others.

Farming has been perceived to be a natural use of land; however, farming is increasingly involving the use of land in what may be perceived as a non-natural use that may be dangerous to others. The non-natural use of land can burden a farmer with a heavier legal responsibility. The general rule is that a person is responsible for damages resulting from the escape of anything related to the non-natural use of land, including the use of non-natural or dangerous substances, even when reasonable care is taken to prevent the escape.[***] This rule has formed the basis of strict liability, and offers potential relief for environmental damages. Some statutes have modified the rule by making reference to "pollution" rather than a non-natural use of land.[†††]

A difficulty arises with establishing what is a "non-natural" use of the land due in part to technological improvements, scientific understanding and a heightened public

[***] *Rylands v. Fletcher* (1868), 37 L.J. Ex. 161, L.R. 3 H.L. 330 (H.L.). Note that a dangerous use or practice if commonly accepted may not attract liability under the Rylands and Fletcher doctrine. Additionally, a harmful activity that is carried out for the public good and not for the private good or profit may not attract liability. See *Danku v. Fort Frances* (Town) (1976), 14 O.R. (2d) 285 (Dist. Ct.).

[†††] For example, under *The Environmental Management and Protection Act*, S.S. 1983-84, c.E-10.2, a person suffering property or personal damages can sue without proof of fault, negligence or wilful intent. The injured party must only prove that he or she suffered damages from the defendant's pollution. This kind of action has yet to be used against a farming operation.

concern for the environment. The concept of "non-natural" use can be analyzed with respect to the nature of a substance used on land. For example, the deposition of arsenic from a defendant's smelter emissions onto a plaintiff's land, which resulted in the death of a cow, attracted strict liability.[69] Arsenic is an extremely poisonous chemical element, compounds of which are used in making insecticides. The court, invoking the *Rylands v. Fletcher* doctrine, held arsenic to be a dangerous material that escaped and awarded the plaintiff damages. In contrast, the use of salt to de-ice highways was held to be a natural use of the land as salt is not non-natural or inherently dangerous, despite the fact that an orchard was injured.[70]

Strict Liability Actions related to Hog Operations and Water Pollution

Manure is a natural substance that has been applied to land for well over a thousand years. In this respect, applying manure would generally not be the subject matter of strict liability doctrine. However, the technique of manure application may attract liability. For example, in *Metson v. R.W.D. Wolf Ltd.*,[71] a top dressing of manure onto frozen farmland polluted a neighbour's water supply. This practice attracted liability under the *Rylands v. Fletcher* doctrine as it was considered a non-natural use of the land. As in the *Mihalchuk* case concerning weed control, *Metson* placed a further qualification on the notion of "natural use of land" by considering the method of use rather than the objective of the activity.

Perhaps the large amounts of manure produced and its subsequent storage by intensive hog operations would be considered a non-natural use of the land. Manure would be much more concentrated in a small region than ever before.

The Statute Law of Pollution

In addition to environmental liability under the common law (nuisance, negligence, and the *Rylands v. Fletcher* rule), liability can also arise from environmental statutes. Legislation to prevent water pollution began in Saskatchewan in 1889 with an Ordinance that imposed a $5 fine on anyone polluting streams with "stable manure or any night soil, carcasses or any filthy or improper matter".[72] Since 1889, both the federal and provincial governments have been passing laws to control the pollution of our natural resources. Environmental statutes range from supplementing or replacing the common law to placing pollution prevention controls on "operations" that have the potential to pollute like intensive hog operations.

Pollution is primarily regulated in Saskatchewan under *The Environmental Management and Protection Act*.[73] Here, pollution is defined as an alteration of the physical, chemical, biological, or aesthetic properties of the environment, including the removal of a substance that: renders the environment harmful to public health; is unsafe for domestic, municipal, industrial, agricultural or other land uses of the environment; or, is harmful to birds, animals or aquatic life. Pollution from hog operations can make water unsafe for human use and can led to the algal growth in streams, rivers, and lakes. Algal growth starts the process of eutrophication or growing oxygen deficiency which has detrimental impacts on fish populations and wetland ecosystems.[74]

The penalties for being convicted under the various acts may be severe. For example, a person convicted under *The Environmental Management and Protection Act* of Saskatchewan may have to pay a fine up to $1,000,000, go to jail for up to 3 years, or perhaps both. Additionally, the environment minister can order the person responsible for the pollution to take any measure necessary to protect or restore the environment.[‡‡‡]

Athough environmental offences are not enforced against farmers on a regular basis it is important for farmers and practitioners to be cautious as strict liability punishments for environmental pollution such as a “stop order” or a “clean up order” from the environment minister can be very costly.[75]

The (Saskatchewan) Agricultural Operations Act

Saskatchewan as well as other Canadian provinces has enacted “Right to Farm” legislation, which modifies the common law to protect agricultural operations from nuisance claims and sets out regulations for the establishment of intensive livestock operations.[76]

The *Agricultural Operations Act*[77] of Saskatchewan requires a person with a nuisance complaint against a farmer to apply to the Agricultural Operations Review Board (Board) for a decision as to whether the activity at the root of the nuisance is a “normally accepted agricultural practice”.[§§§] If the activity at the root of the nuisance is not a “normally accepted agricultural practice” the Board will determine what action the farmer should take to comply with an accepted practice.

A civil action in nuisance can not be initiated until 90 days after the application has been filed with the Board (mediation will extend this time period).[78] If either party does not accept the Board’s decision the case can proceed to court however, in deciding the nuisance claim, a court must give primary consideration to the Board’s decision. A farmer found to follow a “normally accepted agricultural practice” by the Board will likely not be held liable in nuisance.

In addition to providing farmers with protection against unwarranted nuisance claims and a mechanism for resolving disputes (section 3.1.1.3), *The Agricultural Operations Act*[79] also provides protection against the contamination of surface water and groundwater. This protection is mainly achieved through the legislative requirements for intensive livestock operations (ILO) to participate in an extensive permitting process. Saskatchewan’s legislation[80] requires a waste storage plan[****] and a waste management plan[††††] for any “prescribed” ILO as approved by the provincial minister of the

[‡‡‡] Check s. 4?

[§§§] The *Agricultural Operations Act, ibid*., s.2(i) defines a “normally accepted agricultural practice” as a practice that is: “conducted in a prudent and proper manner that is consistent with accepted customs and standards followed by similar agricultural operations under similar circumstances, including the use of innovative technology or advanced management practices in appropriate circumstances; or conducted in conformity with any standards established pursuant to the regulations; and meets accepted standards for establishment and expansion”.

[****] A waste storage plan is a document that describes how the waste from an ILO will be stored.

[††††] A waste management plan is a document that describes how the waste from an ILO will be managed.

environment. ILO operators are also subject to relevant municipal bylaws and, like all farmers may be sued in nuisance or in other causes of action. However, a nuisance claim must first be brought before the appropriate board to determine whether the ILO complies with “normally accepted agricultural practice”.

Although environmental offences under *The Environmental Management Protection Act* are not regularly enforced against farmers, the mechanisms are present to do so. For example, a swine production company was charged and fined under a Manitoba pollution statute for dumping garbage and dead pigs into a pit near La Broquette, Manitoba.[81] The company was also ordered to remediate the site. In Alberta, a feedlot pleaded guilty to polluting a creek on one count under the provincial *Environmental Protection and Enhancement Act* and on another count under the federal *Fisheries Act* (fines totaled $120,000).[82] The intensive hog operations have to abide by strict regulations and are subject to inspections, and fines for non-compliance.

At the intersection of legal considerations and environmental concerns lies potential new costs to hog producers. Producers may be confronted by damage payments, remediation, injunctions, fines or jail time for successful liable claims that “Right to Farm” legislation such as the AOA does not cover. This may increase as the law and legislation move to re-balance the interests of the public and the environment with increasingly more intensive, and less traditional, agricultural practices. Saskatchewan as is shown in Table 11 has some of the most lax legislation in this area in comparison with the West, Canada and the world at large.[83]

Table 15: Comparison of regulations for manure management under some jurisdictions.

Jurisdiction	Limiting nutrient	Minimum storage capacity	Winter hauling ban	Other requirements
Manitoba	nitrogen		from Nov. 10- April 15 for large operations	
British-Columbia	nitrogen		total amount of manure not exceeding 40% of total annual	
Quebec	phosphorus	250 days	on snow. frozen soil, from Nov. to May.	no guns
Denmark	nitrogen	9 months	Oct.-March	incorp. within 12 hr.
The Netherlands	phosphorus	6 months	on snow, frozen soil, between Oct.-march	incorp. within 24 hr.
Saskatchewan	nitrogen	60 to 400 days	None	none

With the heightened public concern over climate change and Greenhouse gas emissions and the signing of the Kyoto Agreement by Canada the federal and provincial governments will be looking for emission reduction strategies for the various industries which make up the Canadian economy. Agriculture will fall under scrutiny and one legislative option under review is possible land-taxes tied to operation emission reductions.[84] If producers establish digesters they will lower their emissions and avoid possible governmental pressure tactics like taxes or fines.

Other information:
Three basic problems emerge when attempting to run a full scale biogas plant:

1. technical problems to which a more or less easy solution can be found
2. farm integration difficulties which require farm level modifications, the incidence of this type of problem can be reduced if more attention is paid to the specifications of the farm at the design stage.
3. management and training (Cortellini L. et al., 1989, p.231)

kills odor problems reduce legal responsibilities, reduces legal responsibilities for water contamination because of waste treatment and no lagoons to risk run-off (http://www.greentie.org/class/ixh0705.htm)

Costs of Biogas Digester

1. need to compare costs of traditional manure handling methods and digesters - how much to build and how much to run
2. how much energy does it take to keep the digester at ambient temperature during the winter

Costs of not having a Digester

1. Legal - fines, time, jail
2. potential taxes or fines from government

Benefits of having a digester

1. how much energy produced and what can it be sold for
2. fertilizer sales (greater than prior raw manure sales or spreading) or feed sales or replacement of feed consumption
3. increased employment
4. reduced legal considerations
5. reduced environmental considerations
6. soil carbon sequestration = carbon credits

Needed to complete report:

need to compare traditional manure handling method to digester method for costs and benefits on a farm-level

Information not yet integrated:

Costs of traditional lagoon manure disposal
agitation of manure in pit or lagoon is highly recommend if the operator intends on applying the manure as fertilizer. The manure should also be tested for N, P and K levels before it is applied as some soils already have high phosphorous content (http://www.fb.com/connect/watershed/manure.htm.

spreading or broadcasting methods are relatively inexpensive but have land requirement, some incorporation requirements, nutrient loss for soil, soil compaction, and considerable odour production whereas direct injection of manure into the soil preserves the nutrient content of the manure and reduces odour production, but has much higher costs in machinery, time, fuel, and labour, and would be unacceptable in zero-till or perennial forage situations (Calculation of Manure Application Rates - Manitoba Agriculture - http://www.gov.mb.ca)

annual costs for covering a 25 000 ft^2 (2,320m^2) lagoon were estimated at $1,100 for an unsupported cover and $2050 for a supported cover to aid in odour control. Lagoons must be carefully agitated and pumped out (http://www.pami.ca/pamipubs/RU698.htm).

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[1] (CSALE, 1996, p.4)
[2] (http://www.adminsrv.usask.ca/psci/psc_db/gas.htm)
[3] (http://www.gov.mb.ca/agriculture/livestock/pork.swine/bab10s08.html) and (http://www.gov.mb.ca/agriculture/livestock/pork/swine/bah11s01.html)
[4] (http:www.lincolnshire.net/dmu/Research/AgHort_Research/hybrids/Project.htm)
[5] (Hazeltine and Bull, 1999, p.140)
[6] (http://gate.gtz.de/biogas/basics/parameter.html) and (http://www.commonlink.com/~methane/indepth.html)
[7] (http://gate.gtz.de/biogas/basics/parameter.html)
[8] (http://www.commonlink.com/~methane/)
[9] (Hazeltine and Bull, 1999, p.151)
[10] (Montuelle, Coillard, and Le Hy, 1992, p.94)
[11] (http://gate.gtz.de/biogas/basics/basics.html) and (http://www.greentie.org/class/ixh0705.htm).
[12] (Zhang, North and Day, 1989, p.1)
[13] (Young Medina et al., 1989, p.156)
[14] (http://www.greentie.org/class/ixh0705.htm)
[15] (http://gate.gtz.de/biogas/basics/parameter.html)
[16] (http://www.folkcenter.dk/rokai/rokai.html)
[17] (http://gate.gtz.de/biogas/costben/costs.html)
[18] (http://gate.gtz.de/biogas/costben/costs.html)
[19] (Aburas et al., 1995, p.102)
[20] (http://gate.gtz.de/biogas/costben/costs.html)

[21] (http://www.folkcenter.dk/rokai/rokai.html) and (Montuelle, Coillard, and Le Hy, 1992, p.99)
[22] (http://gate.gtz.de/biogas/basics/parameter.html)
[23] (http://gate.gtz.de/biogas/basics/basics.html)
[24] (http://gate.gtz.de/biogas/basics/parameter.html)
[25] (Yang and Gan, 1998, p.26-27)
[26] (http://gate.gtz.de/biogas/costben/costs.html)
[27] (http://www.folkcenter.dk/rokai/rokai.html)
[28] (Abduras, et al., 1995, p.103-104)
[29] (http://www.greentie.org/class/ixh0705.htm)
[30] (Zhang, North and Day, 1989, p.2)
[31] (Montuelle, Coillard, and Le Hy, 1992, p.94-95)
[32] (http://www.greentie.org/class/ixh0705.htm)
[33] (http:www.lincolnshire.net/dmu/Research/AgHort_Research/hybrids/anaerobic_digester.htm) and (Zhang, North and Day, 1989, p.3)
[34] (Hazeltine and Bull, 1999, p.152); (http://www.folkcenter.dk/rokai/rokai.html); and (http://www.commonlink.com/~methane/alvin.html)
[35] (http://www.folkcenter.dk/rokai/rokai.html)
[36] (http://www.greentie.org/class/ixh0705.htm)
[37] (Zhang, North and Day, 1989, p.3)
[38] (http://www.folkcenter.dk/rokai/rokai.html)
[39] (Hazeltine and Bull, 1999, p.153); (http://www.commonlink.com/~methane/alvin.html); and (http://www.greentie.org/class/ixh0705.htm)
[40] (http://www.gov.mb.ca/agriuclture/livestock/pork/swine/bah11s01.html)
[41] (Young Medina et al., 1989, p.155)
[42] (Young Medina et al., 1989, p.155); (Hazeltine and Bull, 1999, p.153); and (Yang and Gan, 1998, p.24)
[43] (Yang and Gan, 1998, p.24)
[44] (http://www.commonlink.com/~methane/) and (Yang and Gan, 1998, p.24)
[45] (University of Saskatchewan, et al., 1987, p.86-87) and (http://www.gov.on.ca/omafra/english/livestock/swine/facts/85-109.ht)
[46] (http://www.greentie.org/class/ixh0705.htm)
[47] (http://gate.gtz.de/biogas/basics/basics.html)
[48] (http://www.greentie.org/class/ixh0705.htm) and (http://www.lincolnshire.net/dmu/Research/AgHort_Research/hybrids.Ind_objectives.htm)
[49] (Burton et al., 1997, p.125)
[50] (Burton et al., 1997, p.125)
[51] (http://www.4cleanair.org/comments/GHGPowerPoint?AGRICULTURE/sld010.htm)
[52] (Montuelle, Coillard, and Le Hy, 1992, p.99)
[53] (http://www.4cleanair.org/comments/GHGPowerPoint?AGRICULTURE/sld010.htm)
[54] (Young Medina et al., 1989, p.155) and (University of Saskatchewan, et al., 1987, p.86-87)

[55] (Buckingham et al., 1997); (Phillipson and Bowden, 1998); and (Young Medina et al., 1989, p.142)
[56] (C. Pupp, H. Maathuis & G. Grove)
[57] (C. Pupp, H. Maathuis & G. Grove)
[58] (C. Pupp, H. Maathuis & G. Grove)
[59] (http://www.gov.mb.ca/agriculture/livestock/pork.swine/bab10s08.html)
[60] (Buckingham et al., 1997, p.27-28)
[61] (Bilson, 1991) and (Kalmakoff, 1999, p.225)
[62] See *Tock v. St. John's Metropolitan Area Bd.*, [1989] 2 S.C.R. 1181.
[63] (1986), 40 C.C.L.T. 66 (N.B.C.A.); see also *Fogarty and Crouse v. Daurie, ibid.*

[64] [1993] 1 W.W.R. 245 (Man. Q.B.).
[65] (http://www.gov.mb.ca/agriculture/livestock/pork.swine/bab10s08.html)
[66] (1982), 41 N.B.R. (2d) 8 (Q.B.). See *Roberts v. City of Portage La Prairie*, [1971] S.C.R. 481, where seepage from a defendant's (city) sewage lagoon was held a nuisance.

[67] *Portage La Prairie v. BC Pea Growers Ltd.*

[68] (1983), 13 C.E.L.R. 37 (Ont. Co. Ct.).

[69] *Cairns v. Canadian Refining Co.* (1914), 26 O.W.N. 490 (C.A.).
[70] *Schenck v. R. in right of Ontario* (1981), 34 O.R. (2d) 595 (H.C.J.), affd (1984) 49 O.R. (2d) 556 (C.A.), affd [1987] 2 S.C.R. 289.

[71] (1980), 10 C.E.L.R. 109 (N.S. S.C.T.D.).
[72] (Benson, 1996)
[73] *The Environmental Management and Protection Act*, S.S. 1983-84, c.E-10.2.

[74] (Brady, 1990, p.585)
[75] (*The Environmental Management and Protection Act*, S.S. 1983-84, c.E-10.2.)
[76] (Kalmakoff, 1999)
[77] S.S. 1995, c.A-12.1, ss.14-15.
[78] *Agricultural Operations Act*, *ibid*., s.14.

[79] *Supra* note #.
[80] *Supra* note 47, ss.19-26.

[81] (Bell, 1999, p.19)
[82] (Global and Mail, 1998, A6)
[83] (http://www.gov.mb.ca/agriculture/livestock/pork.swine/bab10s08.html)
[84] (http://www.4cleanair.org/comments/GHGPowerPoint?AGRICULTURE/sld011.htm)