BIOENERGY SERIES 3

Discover Biogas

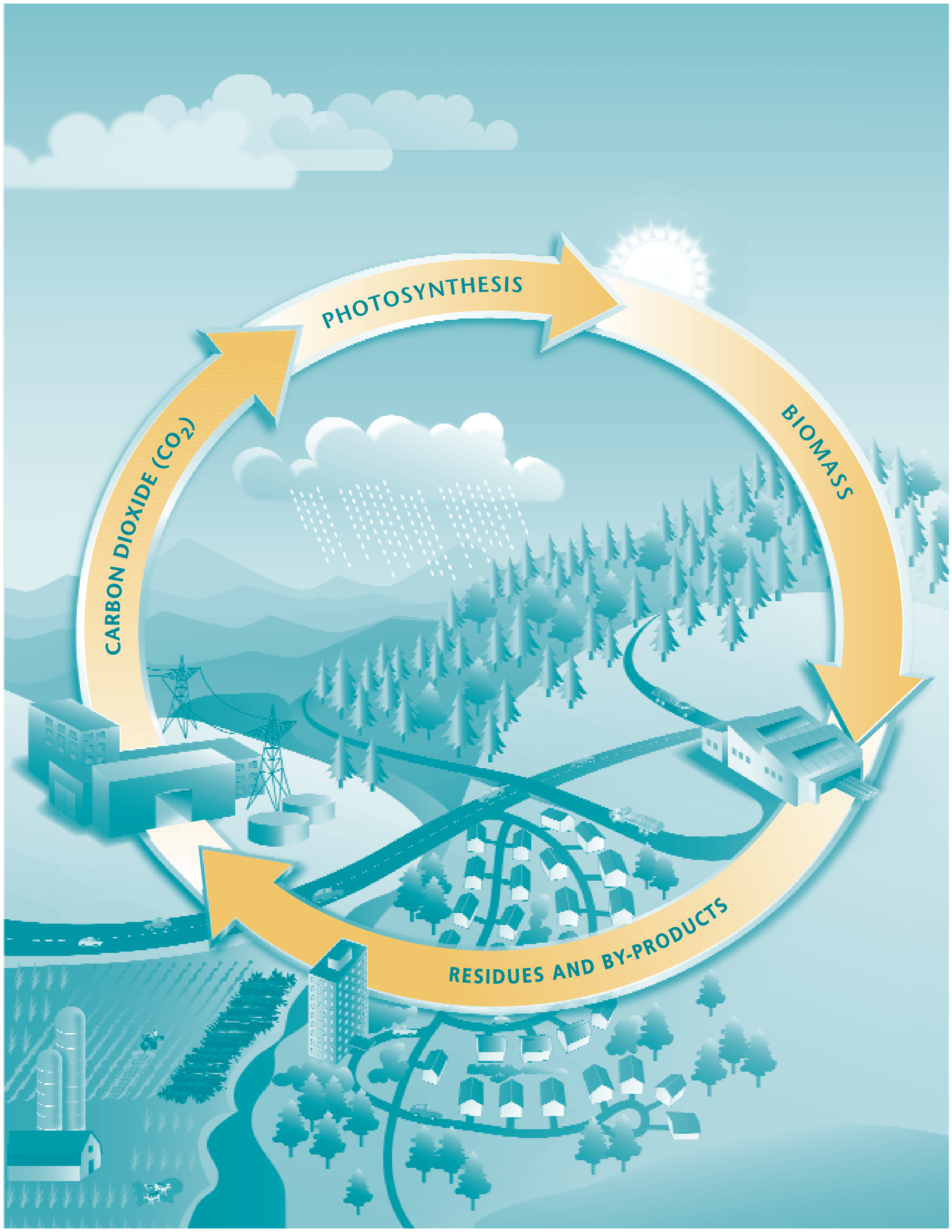
THE PRODUCTION AND USES OF Biogas

How 4 organic wastes are being successfully converted to biogas, thus providing the potential for energy savings and increased profits

Natural Resources Canada and Agriculture and Agri-Food Canada

Ressources naturelles Canada et Agriculture et Agroalimentaire Canada

Canada



Traditional manure management produces greenhouse gas emissions that contribute to climate change. Anaerobic digestion greatly reduces these emissions.

Design and layout by InnovaCom Marketing & Communication, Gatineau, Québec.

Cat. No. M92-253/2002E

ISBN 0-662-33010-2

Aussi disponible en français sous le titre :
À la découverte de la production et des utilisations du biogaz

Discover the Production and Uses of BIOGAS

Many people are not aware that animal manures, waste-waters from food-processing plants, municipal waste-water sludge and many other organic wastes can be valuable sources of renewable energy.

Concerns over the environment and rising costs for energy and for waste-water treatment have caused many Canadians to reflect on the finite nature of fossil fuels and to take another look at renewable sources of energy such as solar, wind and biomass. They are discovering that renewable energy technologies today are well developed and reliable.

Biomass energy, or bioenergy, refers to all forms of renewable energy that are derived from plant materials produced by photosynthesis. Biomass fuels can be derived from wood, agricultural crops and other organic residues such as animal manures, waste-waters from food-processing plants and municipal waste-water sludge. These fuels can be obtained from many sources in Canada, including sawmills, woodworking shops, forest operations, farms, food-processing plants and municipal waste-water treatment facilities.

Bioenergy is regarded as "green" energy for several reasons. Assuming that biomass resources, such as forests, are managed properly, biomass fuels are infinitely renewable. They have already proven to be economically stable sources of energy over time. Bioenergy is neutral in terms of carbon dioxide (CO_2) emissions. Burning biomass fuels merely releases the CO_2 that the plants have absorbed over their life spans. In contrast, the combustion of fossil fuels releases large quantities of long-stored CO_2, which contributes to climate change. Displacing fossil fuels with bioenergy reduces CO_2 emissions.

Using a biological treatment process called anaerobic digestion can produce biogas as a by-product. Biogas typically contains between 60 and 70 percent methane. This high methane content makes biogas an excellent source of renewable energy to replace natural gas and other fossil fuels. Biogas is typically used in factory boilers and in engine generator sets to produce electricity and heat. If internal combustion engines are fuelled with biogas to produce electricity, the facility can use the electricity or export it to the power grid. As well, the facility can use the heat from the engine exhaust and the cooling system for low-temperature heating needs in the plant (such as space heating, drying and pre-heating process materials).

Anaerobic treatment has been historically used to biologically stabilize high-strength wastes at a low cost. In many cases, the biogas has not been used as an energy resource. Rather, it has been burnt in a flare and discharged to the atmosphere.

Concerns over the environment and rising costs for energy and for waste-water treatment have caused a resurgence of interest in anaerobic treatment and a new interest in using biogas produced during this treatment of organic wastes.

Anaerobic digestion is a process that occurs in nature. Swamp gas, which contains methane, is produced from the anaerobic degradation of wetland vegetation that has settled to the bottom of the wetland.

Anaerobic digestion involves bacteria that require an environment that is void of oxygen to survive. Converting organic waste to methane gas by anaerobic digestion can be considered a two-step process. The first step involves a group of anaerobic bacteria – referred to as the acid formers – that produces organic acids as a by-product of the initial organic degradation. The second step involves a group of bacteria – known as the methane formers – that breaks down the organic acids and produces methane as a by-product of the degradation of the organic acids.

One measure of the strength of organic wastes is the chemical oxygen demand (COD). Typically, for every kilogram of COD removed from waste during anaerobic treatment, 0.35 cubic metre of biogas is produced. Table 1 lists four organic wastes, the typical range of COD levels for the wastes, the potential volume of biogas that can be produced assuming an 80 percent COD removal rate, and the energy value of the biogas based on a per-unit volume of waste treated.

Many different types of anaerobic treatment technologies are available, and new advancements in anaerobic treatment are evolving as interest in the technology increases. The technologies vary in terms of the length of time required for treating the wastes; the size, configuration and complexity of the reaction vessel; and the operating temperature. Anaerobic treatment systems range from relatively large, simple plug flow covered lagoons to high-rate, two-stage fluidized bed systems. They also include hybrid systems that combine several technological innovations to reduce the size of the treatment vessel and to increase the treatment efficiency of the system.

Anaerobic treatment systems operate in three temperature regimes. Passive anaerobic systems typically operate at 10–20ºC and are low-rate and lower-efficiency systems. Mesophylic systems, which are the most common, operate at 35–40ºC. These systems offer increased treatment efficiency over passive systems. Finally, thermophilic systems operate at 45–55ºC and are considered high-rate and, in some cases, higher-efficiency systems. But they may require substantially more energy to maintain the thermophilic operating temperature. Thermophilic systems are well suited to high-temperature, high-strength waste-waters.

Anaerobic Digestion

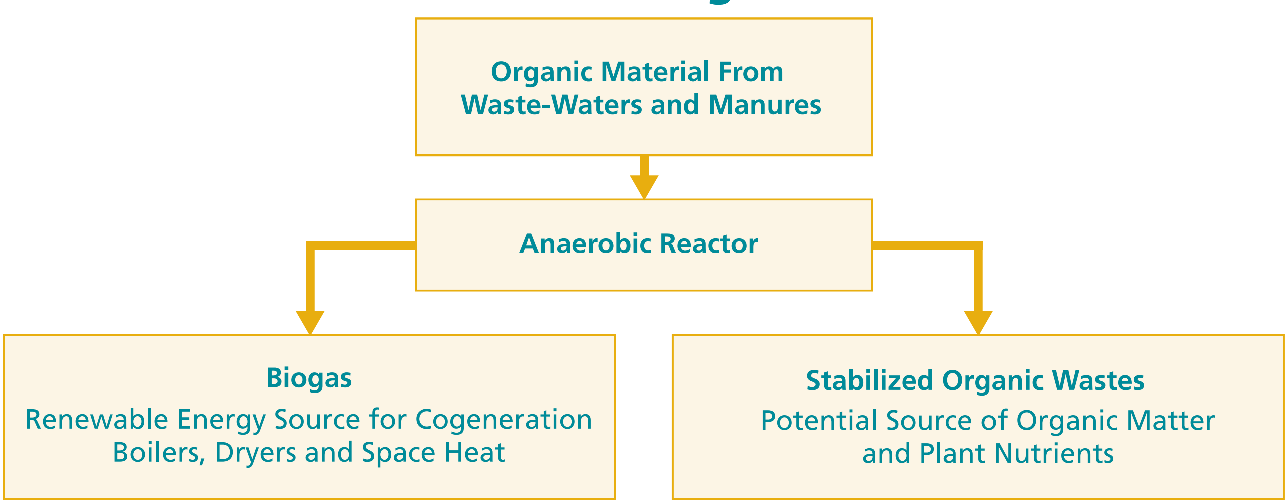


Table 1. Typical Chemical Oxygen Demand (COD) Range for Wastes and Potential for Biogas Production

Waste type	Typical COD range	Typical biogas volume m^3/m^3 waste treated (80% COD removal efficiency)	Typical biogas energy obtained kJ/m^3 waste treated (80% COD removal efficiency)
Liquid swine manure	30 000–50 000 mg/L	8.400–14.000 m^3	196 000–326 000 kJ
Potato-processing waste-water	3 000–6 000 mg/L	0.840–1.680 m^3	20 000–39 000 kJ
Corn-processing waste-water	1 000–4 000 mg/L	0.280–1.120 m^3	7 000–26 000 kJ
Meat-packing plant waste-water	800–1 200 mg/L	0.224–0.336 m^3	5 000–8 000 kJ

Table 2. Typical Anaerobic Digestion Technologies

Anaerobic technology	Typical vessel size per-unit volume treated	Typical operating temperature	Typical treatment time required (hydraulic retention time)	Typical treatment efficiency (COD removal rate)
Plug flow system	25 m^3/m^3 treated per day	35–40°C	20–30 days	60–75% removal
Completely mixed system	13 m^3/m^3 treated per day	35–40°C	6–20 days	70–80% removal
Upflow anaerobic sludge blanket system	3 m^3/m^3 treated per day	35–40°C	0.5–6.0 days	80–95% removal
Fluidized bed system	3 m^3/m^3 treated per day	35–40°C	0.5–1.0 day	80–95% removal
Anaerobic sequencing batch reactor system	15 m^3/m^3 treated per day	18–20°C	10–28 days	60–80% removal

Table 2 lists five types of anaerobic treatment technologies that municipalities, food processors and farm operations use today for treating wastes. The table lists the typical vessel size per-unit volume of waste being treated, the operating temperature, the typical treatment time required (hydraulic retention time) and the typical treatment efficiency (COD removed).

Identifying and Using Potential Renewable Energy Resources

Necessity is the mother of invention, and well-managed companies are continually looking for ways to improve their profit margins. This search often involves looking at ways to reduce waste-management and energy costs. Anaerobic treatment of organic wastes provides the unique opportunity to reduce these costs. Many sectors of society, including municipalities, food-processing industries, rendering industries, animal feed manufacturers and livestock farmers, are examining how anaerobic treatment and biogas use can improve their profitability.

Casco Inc.

Casco Inc. is committed to producing competitively priced food ingredients in an environmentally sound manner. The Casco plant in London, Ontario, generates high-strength waste-water as a by-product of the processes involved with producing sugars, starch and animal feeds from corn. The plant installed an ONDEO Degrémont Anaflux® anaerobic treatment system in 1998 and added a second anaerobic reactor in 2000. The system pre-treats Casco's high-strength waste-water before it is discharged into the municipal sewer system.

"Casco chose this particular system because it provides up to 95 percent removal of BOD (biochemical oxygen demand) while producing only a fraction of the biosolids of an aerobic system," says Nadjia Lafontaine, Casco's environmental co-ordinator. "It also requires a smaller footprint than most other systems, has the capability to treat high-strength waste-water, reduces odours associated with aerobic system upsets and recovers rapidly from system upsets."

Moreover, pre-treating the waste-water significantly reduces the sewer surcharge that Casco pays to the municipality for discharge to the municipal sanitary sewer system. Anaerobic pre-treatment of the waste-water was the most cost-effective treatment option for Casco because of the waste-water's high strength. The system can treat up to 213 cubic metres of waste-water per hour.

The waste-water undergoes coarse screening prior to anaerobic treatment. Casco uses a three-stage system. The initial breakdown of organic wastes into organic acids occurs in an acidification tank, which has a minimum six-hour hydraulic retention time. Flow into and out of this tank varies with the volume of waste-water sent to the system while the tank volume is kept constant.

Ms. Lafontaine explains, "Waste-water flows from the acidification tank to two Anaflux® fluidized bed anaerobic reactors, where the organic acids are converted to methane gas – a renewable energy source – and carbon dioxide." Flow to each reactor varies depending on the waste-water flow rate from the production facilities. However, a portion of the effluent from each reactor is recirculated to the reactor feed pumps and combined with acidified waste-water in order to maintain the required upflow velocity through the system's fluidized bed.

The fluidized bed is made up of finely ground and graded pumice that provides attachment surfaces for the anaerobic bacteria. This results in a compact system with a large mass of biosolids in a small volume. The two Anaflux® reactors provide operational flexibility. They can be operated in parallel or series, depending on the strength of the waste-water and on the health and appetite of the microbes in each of the reactors. Effluent from the reactors

Casco Inc., London, Ontario

is then sent to a flash tank and aerated for several hours. Here, any remaining volatile compounds are flashed and oxidized before being discharged to the municipal sanitary sewer.

The capital cost for the Casco anaerobic treatment system, including the 2000 expansion, was approximately $8 million. The annual operating costs for the system – including labour, chemicals, maintenance and energy – is about $950,000. Casco is now examining options for using the biogas produced by its anaerobic treatment system. Studies conducted by Casco to date indicate that the biogas has a value of $200,000 to $300,000, depending on the end use in the plant. Although the biogas is now being burned in a flare, some of the options that Casco is considering include using the biogas as a fuel source for existing plant dryers or to generate steam and electricity.

Casco Inc.'s sugar, starch and animal feed plant

Casco Inc.'s ONDEO Degrémont Anaflux®
anaerobic treatment system

Haubenschild Farms, Inc.

Haubenschild Farms, Inc. is a 400-hectare (1000-acre) family-owned farm near Princeton, Minnesota. In 1998, the owners planned to increase the milking herd size from 430 to 900 cows and started to consider the environmental and economic benefits to the farm's operation if they installed an anaerobic manure digester.

Haubenschild Farms considered this digester for the following reasons:

- Odour control
- Generation of electricity
- Thermal energy production
- Potential increase in the value of manure as a fertilizer
- Pathogen reduction
- Weed-seed destruction
- Reduction of greenhouse gas emissions
- Possible sale of digested fibres

The U.S. government AgSTAR program, which encourages the use of methane recovery in livestock facilities across the United States, selected the Haubenschild farm to demonstrate farm-scale anaerobic digestion. The Haubenschild Farms digester project was a joint venture with assistance from AgSTAR and from Minnesota's Department of Agriculture, Department of Commerce and Office of Environmental Assistance. The Haubenschild digester and cogeneration system was constructed in 1999 at a cost of approximately US$355,000.

Haubenschild Farms Inc., Princeton, Minnesota

Haubenschild Farms' dairy operation and digestion system

The system is a heated plug flow system comprising a covered, 1325-cubic-metre (46 800-cubic-foot) concrete tank installed in the ground. A 150-kW cogeneration system operated by a Caterpillar® 3406 engine fuelled by biogas is used to produce heat and electricity. The electricity is sold to the local power utility. The recovered heat is used to heat the digester and provide supplemental barn heat. A suspended-pipe hot-water heat exchanger in the digester is used to heat the digester to between 35° and 40°C.

The plug flow system was selected because it was considered well suited for treating high-solids dairy manure (11–14 percent), which is typical of manures collected by floor scraping. Manure is pumped into one end of the plug flow reactor and flows through as a plug, with no mixing other than the natural mixing that occurs as a result of biogas evolution. The system was designed to handle the manure from the projected herd-expansion size of 900 milking cows.

Operating data were collected for the Haubenschild digester during January to June 2000, when the unit was treating manure from about 425 cows. During this monitoring period, the reactor hydraulic retention time was approximately double the design value. The digester produced 3.9 cubic metres (139 cubic feet) of biogas per cow per day, and the cogeneration system produced 5.5 kWh of electricity per cow per day during the monitoring period. Dennis Haubenschild, happy with the system performance so far, says, "It's particularly satisfying to see it working better than we expected it to." From the collected data, revenues of $US62,200 were predicted annually from the sale of electricity to the hydro grid at $US0.0725 per kWh, based on treating manure from 425 cows.

Haubenschild Farms' digestion system

Henry Fisher of East Central Energy, the electric utility that purchases excess hydro from Haubenschild, was quoted in the October 2000 edition of *Dairy Today* magazine as saying, "We view this project as an opportunity to make full use of renewable energy resources and promote sustainable agriculture."

The Haubenschild cogeneration system also produced sufficient heat during the monitoring period to predict annual savings of $US4,000 for farm-heating costs. Mr. Haubenschild, particularly pleased with the system performance, indicated that during September 1999 to March 2001, "we didn't use any propane all winter" because waste heat from the cogeneration system was used to heat the barn floors and office space.

Finnie Distributing (1997) Inc.

Finnie Distributing (1997) Inc. is a food-processing by-product recovery facility located near St. Marys, Ontario. Finnie produces animal feed and specialty animal feed ingredients from food-processing by-products. High-strength waste-waters are produced as a result of process and cleaning operations.

Finnie is a family-owned business committed to sound business management. In 2000, Finnie examined options to upgrade its waste-water management system. Finnie selected anaerobic treatment over aerobic treatment because the former had lower operating costs, and energy savings were possible from using biogas in the plant boilers (in place of purchased natural gas). Gary Richardson, owner of Finnie, explains, "Anaerobic digestion appealed to us because we are protecting the environment by reducing greenhouse gas emissions."

Geomatrix Consultants designed Finnie's anaerobic system based on anaerobic treatability studies that were completed using samples of Finnie's waste-water. Construction of the system began in the early summer of 2001. The system started up in the spring of 2002. The Finnie anaerobic system is a completely mixed, continuous-flow system. The anaerobic digestion tank is an 1800-cubic-metre, all-concrete tank with a centre mount mixer. The system was designed to treat 72 cubic metres of waste-water daily. Waste-water is pumped continuously to the digester.

The average temperature of the Finnie waste-water is between 35° and 40°C, and no process heating is required.

The treated, anaerobically digested waste-water is stored in two concrete storage tanks and applied to agricultural land as an organic soil conditioner. An additional benefit of the anaerobic treatment system is that it produces a stabilized effluent that can be stored without producing objectionable odours.

Finnie's anaerobic digestion system cost approximately $425,000. The annual operating costs are projected to be $20,000.

Finnie's system is expected to produce 625 cubic metres of biogas per day once it is fully operational. This is equivalent in energy value to $32,700 per year. Finnie is burning the biogas in a flare as the system gets up and running. After the system is fully operational, Finnie plans on using the biogas in the plant boilers.

Advances in Anaerobic Treatment

Research into advancing anaerobic digestion technology has been ongoing for many years. The research has produced a number of patented systems that provide a variety of advantages in terms of system efficiency, size, capital cost, treatment flexibility, process stability and operating costs. The research into anaerobic digestion continues, carried out by private industry, the scientific community, educational institutions and collaborative efforts between industry and government.

One example of ongoing anaerobic research is the development of a psychrophilic sequencing batch reactor (SBR) anaerobic treatment system to treat liquid animal manures. The system development is a joint venture between Agriculture and Agri-Food Canada and a private sector company. Dr. Daniel Massé, the research scientist with Agriculture and Agri-Food Canada responsible for the system design, says, “One of the major advantages of this system is the low energy input.” The system operates at relatively low temperatures, is mixed only twice a week for a short period and is fed intermittently once a week – all of which result in low energy consumption for operation of the system. The low system-operating temperature means that a greater amount of biogas energy from the system can be used to replace other forms of energy use.

“Another very important advantage of this system is the high process stability,” says Dr. Massé. This means that changes in the manure characteristics and short-term temperature variations have little effect on system performance.

The SBR system is a batch process. The system consists of two reaction vessels that are sequenced between filling, treating, settling, emptying and idle cycles. While one reactor is actively treating manure, the other vessel is being filled. During the treatment phase of the process, the reactor contents are mixed twice a week for about 30 minutes. Once the contents of the active vessel have been treated, the vessel is allowed to sit to settle solids and bacteria out of the liquid phase of the treated manure. The settling phase ensures that sufficient bacteria are retained in the reactor to provide treatment for the next batch of manure and to allow solids to settle to produce a low solids supernatant for discharge. After the empty cycle is completed, the fill-and-treat processes are started again. The idle cycle provides flexibility in starting the SBR process's fill-and-treat cycles over again between batches. The system is operated between 18° and 20°C. A hot-water heat exchanger is used to maintain the desired reactor temperature.

The psychrophilic SBR anaerobic system has been tested at lab, pilot and full-scale stages. A full-scale system has been operating on a 200-sow farrow to finish farm in Quebec since May 2001. The full-scale system is treating the manure generated from about 1200 pigs in the grower finishing units on the farm. The two reaction vessels have a volume of 175 cubic metres each, and the design hydraulic residence time for each reactor is 28 days. The system currently treats an average of 1000 cubic metres of manure annually and produces 50 cubic metres of biogas per cubic metre of manure treated. The system has a maximum treatment capacity of 2200 cubic metres of manure annually.

A micro-turbine cogeneration system will be installed at the farm shortly to utilize the biogas. The cogeneration system is expected to reduce the farm's energy costs by between $15,000 and $27,000 a year. The annual energy costs for the farm are $12,000 for hydro and $15,000 for heat. The operating costs for the anaerobic system are projected to be $4,000 a year.

The SBR system provides a number of advantages to the farm operator beyond energy savings. It deodorizes the manure, increases the availability of manure nutrients for plant uptake and concentrates 70 percent of the manure phosphorus in 30 percent of the manure's original volume (after the natural decantation step).

Conclusion

Biogas from the anaerobic treatment of organic wastes is a valuable renewable energy source that can be used to reduce the consumption of fossil fuels. Fossil fuels are a non-renewable source of energy and contribute significantly to greenhouse gas (GHG) emissions that contribute to climate change. Using renewable energy forms such as biogas helps reduce emissions of GHGs.

The examples in this publication demonstrate how anaerobic digestion can offer a unique opportunity for industry, municipalities and farm operations to turn their wastes into "green" energy in the form of biogas and increase profitability by reducing expenditures for energy and waste management.

For More Information

For more information on renewable energy, including other bioenergy and biomass resources, contact

Renewable and Electrical Energy Division
Natural Resources Canada
580 Booth Street, 17th Floor
Ottawa ON K1A 0E4
Web site: **www.nrcan.gc.ca/redi**

Visit the Web site for Natural Resources Canada's Renewable Energy Network (CanREN) at **www.canren.gc.ca.**

Printed on recycled paper

PRINTED IN CANADA IMPRIMÉ AU CANADA