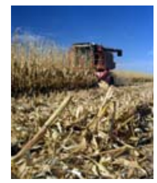
Energy from Biomass

Lecture #8

Background

- **What is Biomass Energy?**
  It is energy derived from organic matter; organic components from municipal and industrial waste, plants, agricultural and forestry residues, home waste and landfills
  - Forests,Farming

  =>Biomass feedstocks, i.e. fast growing trees and grasses.

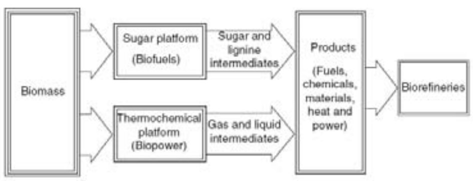


- **Biomass generates about the same amount of carbon dioxide as do fossil fuels (when burned). However, every time a plant grows, carbon dioxide is removed from the atmosphere.**
- **The net emission of carbon dioxide will be zero as long as plants continue to be replenished for biomass energy purposes.**
- **If biomass is converted through gasification or pyrolisis the net balance can even result in removal of carbon dioxide.**

U.S. Potential in Biomass

Classification	Biomass type	Amount
Municipal solid waste/Landfills	quantity of raw material	167 million tones
	direct use from combustion	217,722 TJ
	electricity generation capacity	2,862,000 kW
	electricity generating	71,405 TJ
	total energy production	289,127 TJ
Forestry/wood-processing	electricity generating capacity	6,726,000 kW
	electricity generation	124,712 TJ
	direct use from combustion	2,306,026 TJ
	total energy production	2,430,738 TJ
Agricultural residues-corn	quantity of raw material	13.5 million tones
	ethanol fuel production capacity	152,376 TJ/year
	yield of ethanol	8. 8 GJ/tone
	ethanol fuel production	118,010 TJ
Agricultural residues - soy bean oil and waste food oils	biodiesel production capacity	6,708 TJ/year
	yield of biodiesel	40 GJ/tone
	biodiesel production	671 TJ
Wood pellets	quantity of raw material available	0.582 million tones
	direct use from combustion	8,872 TJ
Other biomass	electricity generating capacity	10,602,000 kW
	electricity generation	11,328 TJ
	direct use from combustion	102,084 TJ
	total energy production	113,412 TJ

Biomass Energy Conversion



Biomass Gasification

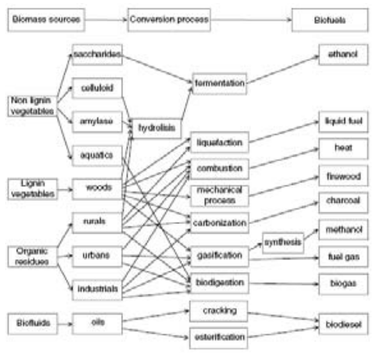
1. The combined heat and power generation (via biomass gasification techniques connected to gas-fired engines or gas turbines) can achieve significantly higher electrical efficiencies, between 22 and 37%, than those of biomass combustion technologies with steam generation and steam turbine, 15 to 18%. If the gas produced is used in fuel cells for power generation, an even higher overall electrical efficiency can be attained, in the range 25 to 50%, even in small-scale biomass gasification plants and under partial load operation.
2. Due to the improved electrical efficiency of the energy conversion via gasification, the potential reduction in CO_2 is greater than with combustion. The formation of NO_x compounds can also be largely prevented, and the removal of pollutants is easier for various substances. The NO_x advantage, however, may be partly lost if the gas is subsequently used in gas-fired engines or gas turbines. Significantly lower emissions of NO_x, CO, and hydrocarbons can be expected when the gas produced is used in fuel cells rather than in gas-fired engines or gas turbines.

Pyrolysis

- Biomass pyrolysis refers to a process where biomass is exposed to high temperatures in the absence of air, causing the biomass to decompose. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide).
- Pyrolysis as a first stage in a two-stage gasification plant for straw and other agricultural feedstocks that pose technical difficulties in gasification does deserve consideration.

- Direct Combustion is the old way of using biomass. The biomass is completely transformed into heat, but the efficiency is just about 10 percent.
- The gasification pushes to the maximum level the cracking of biomass by completely transforming it into a combustible gas before burning it.
- The charcoal production, the slow pyrolysis of wood at temperature 500 °C is a process that charcoal makers have exploited for thousands years. Charcoal is a smokeless fuel which is still used for heating purposes.

Conversion of Biomass on Biofuels



Biogas Volume from Organic Residues

Biomass	Production of Biogas (m^3/ton)	Methane (%)
Sunflower leaves	300	58
Rice straws	300	Variable
Wheat straws	300	Variable
Bean straws	380	59
Soy straws	300	57
Linen stem	359	59
Grapevine leaves	270	Variable
Potatoes leaves	270	Variable
Dry leaves of trees	245	58

Background

- **Over 6 million acres at risk of fire in CO**
  - 2.5 million acres along front range
- **Forest Restoration Act**
  - December 2003
  - Grants to Bio-Energy Companies
  - Designed to lower Risk of Forest Fires

Anaerobic Compost

- **Animal manure is a biomass found in considerable quantities on rural properties.**
- **Anaerobic compost is formed from a mixture of organic manure with animal–water residues in three stages.**
- **In phase 1 (the solid stage), substances such has carbohydrates, lipids, and proteins are attacked by ordinary fermentative bacteria for the production of fatty acids, glucose, and amino acids.**
- **In phase 2 (the liquid stage), the substances formed previously are attacked by the propionic-bacteria, acetogenic bacteria, and acidogenic bacteria, forming organic acids, mainly propionic and acetic, forming carbon dioxide, acetates, and H2.**

Anaerobic Compost

- **In phase 3 (the gaseous stage), the methanegenic bacteria act on the organic acids to produce primarily methane CH4 and carbon dioxide CO2 (biogas).**
- **The third stage is the most important, because bacteria demand special care; they are responsible for limiting the speed of a chain of reactions. This is due primarily to the formation of microbulbs of methane and carbon dioxide around the methanegenic bacteria.**

Types of Biomass Utilizations

- **Co-Firing**
  - Adding Biomass as Substitute fuel
- **Ethanol**
  - Biomass Converted to Ethanol using Geothermal
- **CHP**
  - Burning Biomass in Combined Heat and Power

Co-Firing

- **What is Co-Firing**
  - Supplementing Biomass for other Fuels
- **Combined with Coal**
  - Up to 5% by weight
  - Lowers Emissions of SO_x and CO_2
  - Low Cost Fuel

Mixing Coal and Biomass (Wood Waste)

Co-Firing

- **Plant in Cañon City uses 20-25 tons/day**
- **Co-Firing Started September 2001**
- **Has Burned over 200 tons since May 2002**

Combined Heat and Power

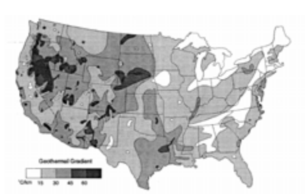
- **What is CHP?**
  - Using Biomass as Sole Fuel
  - Burning Biomass to Heat Boiler
  - Steam used to drive Turbine
  - Steam used for heating

Combined Heat and Power

- **Use of biomass from surrounding areas**
- **30 kW-5 MW Systems**
- **Use Steam to drive turbine**
- **Exhaust Steam used for Heating**

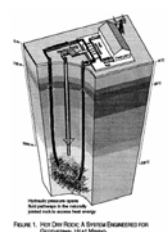
Ethanol

- Uses HDR Geothermal Energy
- Widespread over Western U.S.
- Near Transportation and Biomass Supply



Ethanol

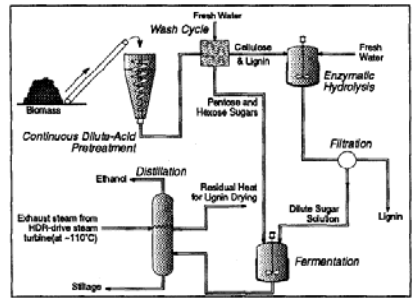
- Because of size of HDR Resource, generally combined with other Renewable Energies
- Used to convert Biomass to Ethanol
- Used to run Turbine during off peak hours



Ethanol

- Preferred biomass mixed grassland
- Switchgrass is major biomass from plains
- Three Main Steps
  - **Wash Cycle**
  - **Fermentation**
  - **Distill out Ethanol**

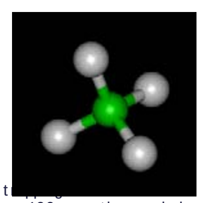
Ethanol



Electrical Power from METHANE

METHANE

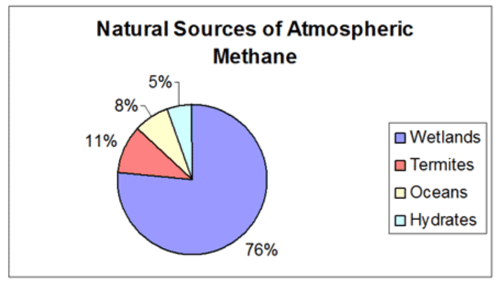
- **Chemical Formula - CH_4**
- **Simplest Hydrocarbon**
- **Natural Gas**
- **Odorless & Colorless**
- **$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$**
- **Greenhouse Gas**
  - Global Warming Potential = 21
    - Methane is 21 times more effective at t atmosphere when compared to CO2 over a 100-year time period.



- Methane is a colorless, odorless gas with a wide distribution in nature. It is the principal component of natural gas, a mixture containing about 75% methane, 15% ethane, and 5% other hydrocarbons, such as propanevand butane.
- The "firedamp" of coalmines is chiefly methane. It is the main component of biogas. It is colorless and odorless, highly flammable and, when entered in combustion, presents a lilac-blue flame and small red stains.

METHANE SOURCES

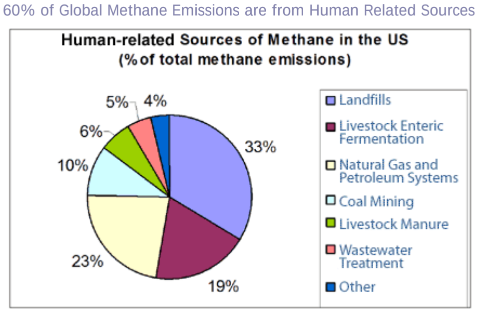
40% of Global Methane Emissions are from Natural Sources



Source: Prepared from data contained in IPCC, 2001c

METHANE SOURCES

60% of Global Methane Emissions are from Human Related Sources

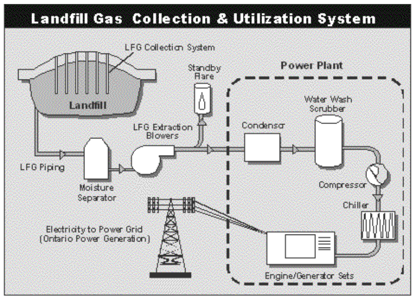


Source: US Emissions Inventory 2003: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001

Landfills

Landfill System

1. Collect Gas through pipes
2. Remove Moisture and Particulates
3. Pressurize
4. Cool
5. Combine with Natural Gas
6. Combustion turbines



Waterloo Landfill Gas to Energy Project
http://www.ec.gc.ca/nopp/lfg/en/issue1.cfm

Waterloo Landfill

•Waterloo, Ontario Canada

•$7.5 million project

•5 million tonnes of refuse

•80 gas collection wells

•8.0MW power generation

Cow Gas

•Enteric Fermentation

•Cattle, Buffalo, Sheep Goats, Swine, Horses

•Fore-Stomach / Rumen

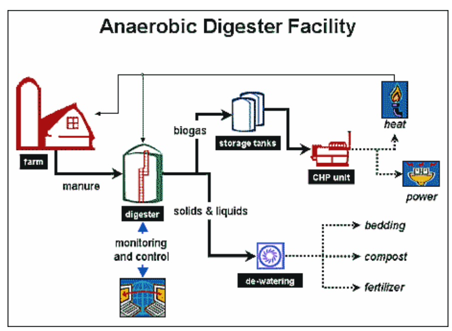
•Exhaled

•Every year, the average dairy cow produces 19.3 pounds of gases

•San Joaquin Valley in California – in top 3 worst pollution problems in U.S.

•Emissions from Dairy Cows greater than cars and pesticides

Methane from Cow Manure



Coal Mine Methane

Combustion of Coal Mine Methane

675 kW Synchronous Skid-Mounted Generator sets at Nelms No. 1 Mine, Ohio (Photo courtesy Northwest Fuel Development, Inc. and U.S. DOE)

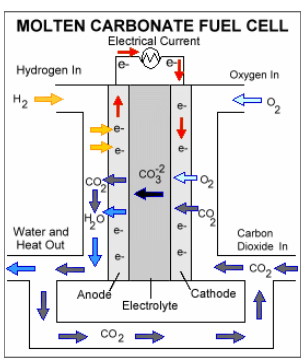
Molten Carbonate Fuel Cell

Operate at extremely high temp of 650°C (1,200°F)+

Efficiency ~ 60% vs 42% for a phosphoric acid fuel cell

With waste heat use, Efficiency ~ 85%

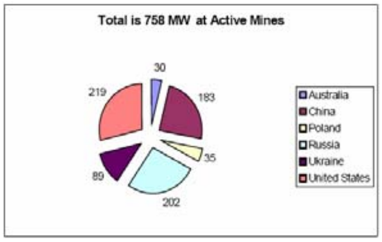
Do not require an external reformer to convert energy-dense fuels to hydrogen. Due to the high temperatures, these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming



Coal Mine Methane Use in Fuel Cells

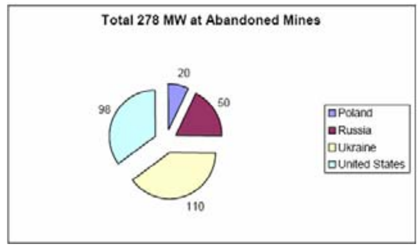
FuelCell Energy DFC Power Plant Installed and Operating Hopedale, Ohio Test Site

Active Coal Mine Potential Power



1999 Coal Mine Methane Potential in Selected Countries Based on Un-utilized Capacity of Captured Methane. Units Shown are MW of Fuel Cell Power

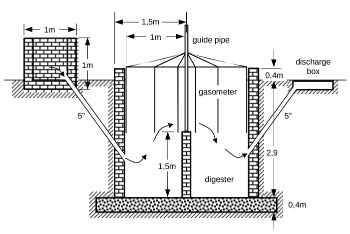
Abandoned Coal Mine Potential Power



1999 Potential Fuel Cell Power at abandoned mines in selected Countries

Production of Biogas in Digesters

- In the dimensions suggested, the biodigester produces $6m^3$ of gas per day, corresponding to 8,568 kWh ($1m^3$/day = 1,428 kWh). The tank will be charged with 240 liters of biomass/day, out of which 120 liters are water and 120 liters are bovine manure. In that case, twelve to thirteen adult, semi-stabled bovine animals are necessary for this production.



- The charge tank can be used either as the pre-fermentation tank, or for mixing the material. Therefore, it should have a volume a little larger than the daily charge, and a little bit above the liquid level of the digester. The discharge tank is mostly constructed for the purpose of protecting the output flow.
- Cow dung gas is 55-65% methane, 30-35% carbon dioxide, with some hydrogen, nitrogen and other traces. Its heating value is around 600 B.T.U. per cubic foot.
- About one cubic foot of gas may be generated from one pound of cow manure at around 28°C. This is enough gas to cook a day's meals for 4-6 people..
- About 1.7 cubic meters of biogas equals one liter of gasoline. The manure produced by one cow in one year can be converted to methane which is the equivalent of over 200 liters of gasoline.

Fermentation

- There are two basic types of organic decomposition that can occur: aerobic (in the presence of oxygen), and anaerobic (in the absence of oxygen) decomposition. All organic material, both animal and vegetable can be broken down by these two processes, but the products of decomposition will be quite different in the two cases. Aerobic decomposition (fermentation) will produce carbon dioxide, ammonia and some other gases in small quantities, heat in large quantities and a final product that can be used as a fertiliser. Anaerobic decomposition will produce methane, carbon dioxide, some hydrogen and other gases in traces, very little heat and a final product with a higher nitrogen content than is produced by aerobic fermentation.

- Anaerobic decomposition is a two-stage process as specific bacteria feed on certain organic materials. In the first stage, acidic bacteria dismantle the complex organic molecules into peptides, glycerol, alcohol and the simpler sugars. When these compounds have been produced in sufficient quantities, a second type of bacteria starts to convert these simpler compounds into methane. These methane producing bacteria are particularly influenced by the ambient conditions, which can slow or halt the process completely if they do not lie within a fairly narrow band

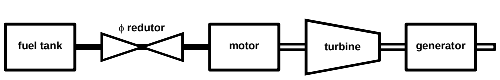
- ACIDITY

  Anaerobic digestion will occur best within a pH range of 6.8 to 8.0. More acidic or basic mixtures will ferment at a lower speed. The introduction of raw material will often lower the pH (make the mixture more acidic). Digestion will stop or slow dramatically until the bacteria have absorbed the acids. A high pH will encourage the production of acidic carbon dioxide to neutralize the mixture.

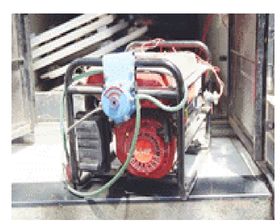
- TEMPERATURE

  Anaerobic breakdown of waste occurs at temperatures lying between 0°C and 69°C, but the action of the digesting bacteria will decrease sharply below 16°C. Production of gas is most rapid between 29°C and 41°C or between 49°C and 60°C. This is due to the fact that two different types of bacteria multiply best in these two different ranges, but the high temperature bacteria are much more sensitive to ambient influences. A temperature between 32°C and 35°C has proven most efficient for stable and continuous production of methane.

- Many manufactured gen-set turbines work with gas. Because majority of the commercial smaller commercial units are in the range of high powers (1.6 MW to 216 MW), some adaptations are required. For micro power plants, alcohol and gasoline motors can be made to operate with methane without any impact on their operational integrity. This adaptation is made by installing a biogas bottle in the place of conventional fuel. For the gas flow regulation, a reducer is placed close to the motor. As the biogas flow operates at low pressures, it demands a larger aperture in the injector, (with a diameter of 1.5 to 2 mm). The adaptation of equipment to work with PLG gases as biogas simply means replacement of the injector or an increase of the diameter of biogas flow to the motor. Some care must be taken with the lubrication of engines using solely biogas due to the "dry" nature of the fuel and some residual hydrogen sulphide, otherwise these are a simple conversion of a gasoline engine.



Biogas and GenSet



Average Consumption of Some Biogas Motors

motor power HP	average consumption m^3 / hour
1.0	0.45
2.0	0.92
5.5	2.24
9.0	3.16

Equivalent Energy per Cubic Meter of Bio-gas to Obtain 6 kcal of Heat

fuel	equivalent amounts
gasoline	0.98 liters
alcohol	1.34 liters
crude oil	0.72 liters
natural gas	1.50 m3
coal	1.51 m3
electricity	2.21 kWh

Gasified Biomass Electric Generator System