PURDUE EXTENSION | LOCAL FACES COUNTLESS CONNECTIONS

Introduction of Anaerobic Digestion

Ji-Qin (Jee-Chin) Ni

Assistant Professor
Department of Agricultural and Biological Engineering
jiqin@purdue.edu

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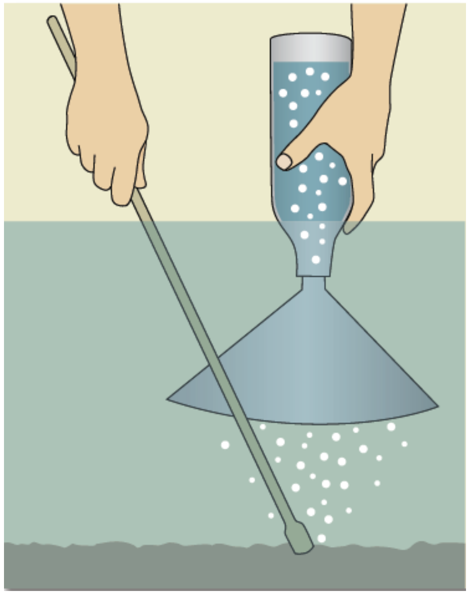
PURDUE UNIVERSITY

Biogas: Product of AD

- A combustible mixture of gases
- Other names: manure gas, methane gas, marsh gas, etc.

Compound	%
Methane (CH_4)	50–75
Carbon dioxide (CO_2)	25–50
Hydrogen sulfide (H_2S)	0–3
Hydrogen (H_2)	0–1
Nitrogen (N_2)	Trace
Ammonia (NH_3)	Trace
Oxygen (O_2)	Trace



Source: Jørgensen, 2009

Methane: A Gaseous Fuel

- Methane
  - Colorless
  - Odorless
  - Boiling point -162°C
  - Density ~ 0.75 kg/m^3
  - Burns with a blue flame

General Features of Biogas

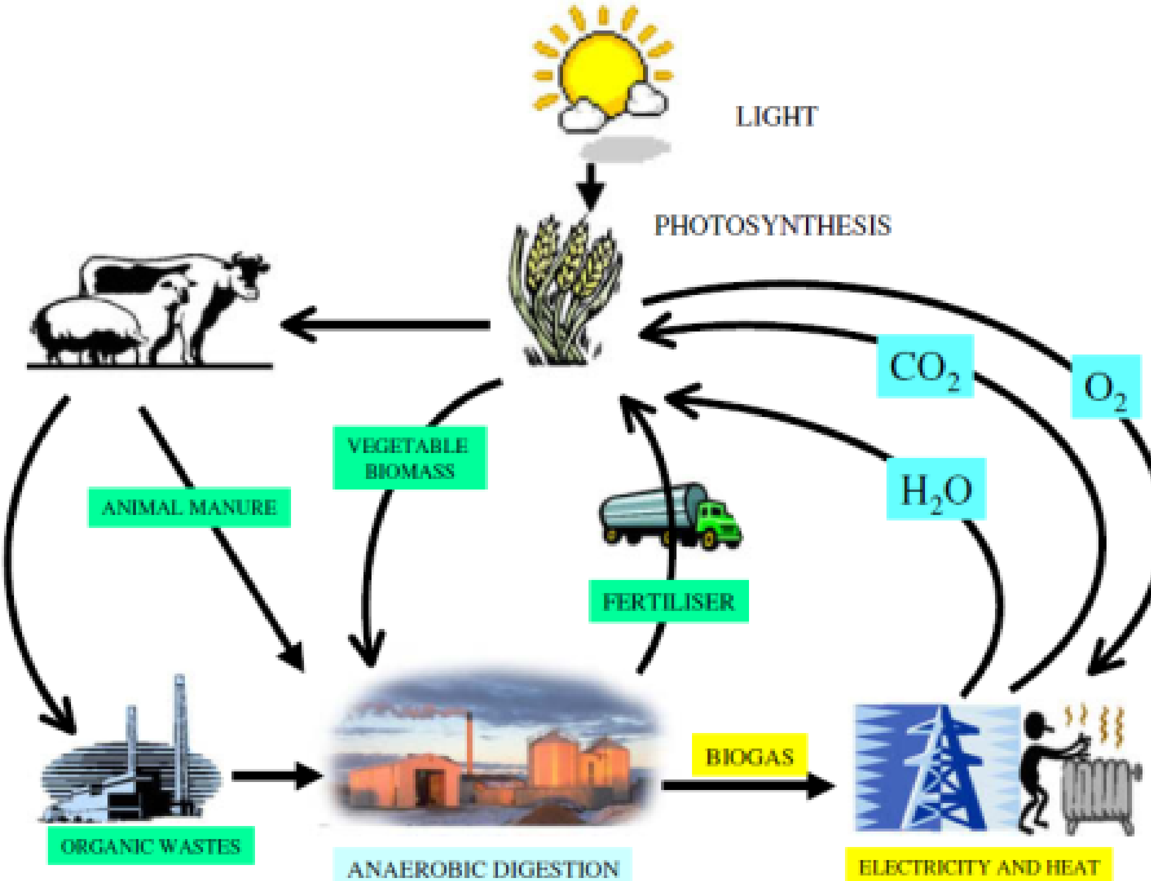
- With 55 – 70% methane
  - Smells bad eggs (due to trace amount of hydrogen sulfide)
  - Mean calorific value: ~20 MJ/m^3 (~6 kWh/m^3)
  - Explosion limits: 6 – 12% biogas in air!
  - Ignition temperature: 650 – 750 °C
  - Critical temperature: -82.5 °C
  - Critical pressure: 75 – 89 bar
  - Normal density: 1.2 kg/m^3
  - Molar mass: 16.043 kg/kmol

Sectors of Application

- Wastewater treatment sludge
- Municipal solid wastes (landfills)
- Animal waste treatment
  - Households or farms
  - Rural community
- Agro-industry (e.g., breweries)
- Food wastes (e.g., supermarkets)
- Energy crops

Biogas in Sustainable Cycle

Sustainable cycle of anaerobic co-digestion of animal manure and organic wastes



Source: Al Seadi, 2002

Benefits for Rural Community

- Improvement of hygienic conditions
  - Reduction of pathogens, worm eggs and flies
- Reduction of workload, mainly for women, in firewood collection and cooking
- Economic benefits through energy and fertilizer substitution
- Increasing yields of animal husbandry and agriculture

Scales of Biogas Digesters

- Large and medium-scale systems:
  - Digester volume up to >10,000 m^3
  - Industrial processing
  - Sludge treatment
  - Large livestock farms
  - Feed materials up to >500 tons/day
- Small-Scale systems
  - Family-size or household system
  - Digester volume: 4 – 10 m^3
  - Feed material: 10 – 60 kg/day

A Wastewater Treatment Utility

- Originally constructed in 1958, expanded in 1970 and upgraded in 1997 in West Lafayette, Indiana;
- Serves 29,000 residents, plus Purdue University and the old regional sewer district;
- Uses micro turbines to generate 70 kW electricity.

Source: http://www.westlafayette.in.gov/department/division.php?fDD=11-185

Some Complete Mixing Digesters

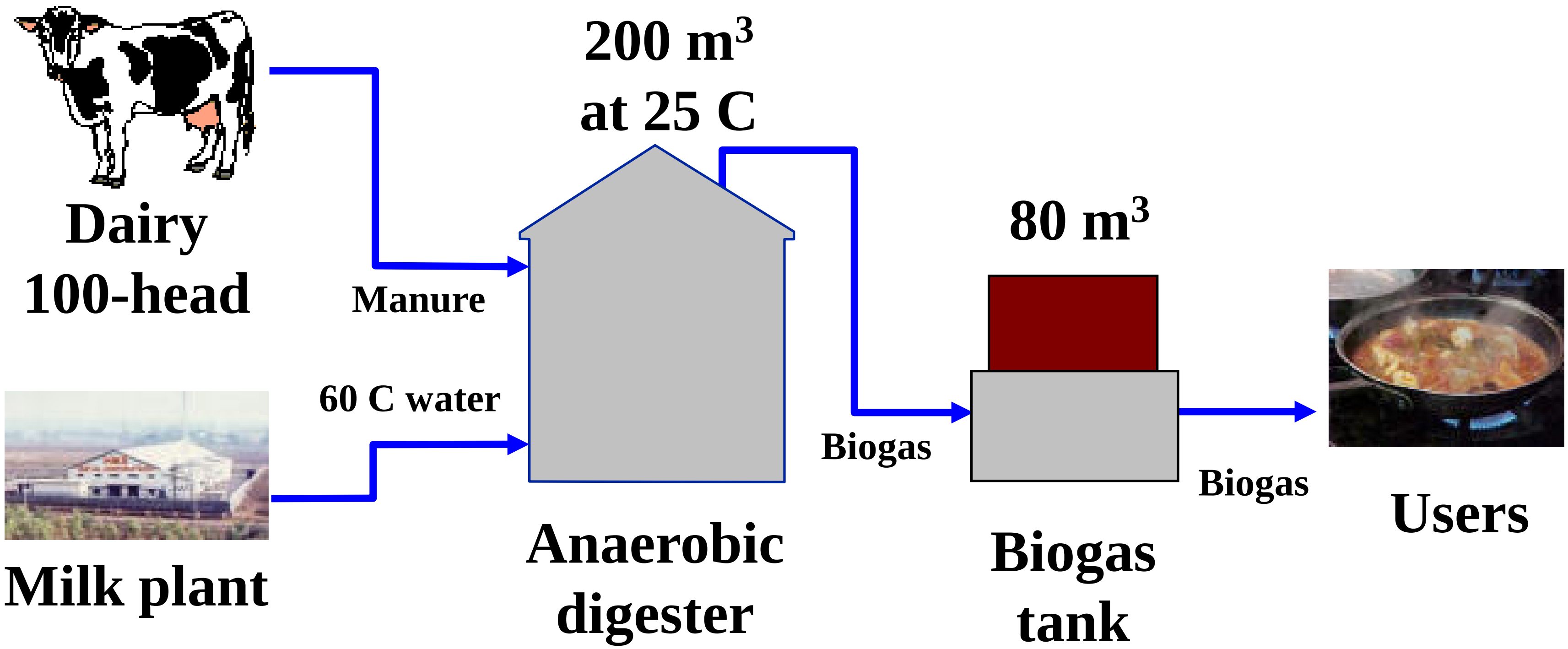
Fair Oaks Dairy farm digester in Indiana, USA

Aarhus University, Denmark

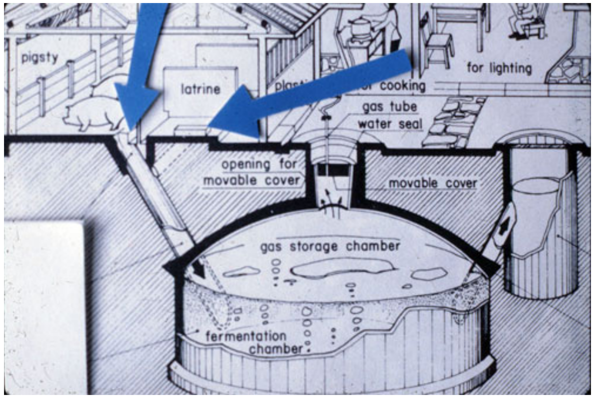
Quasar digester in Ohio, USA

Two swine farm digester systems, China

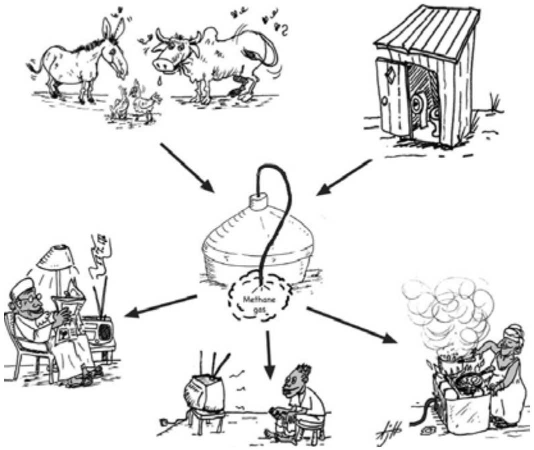
Biogas from Dairy Manure in China



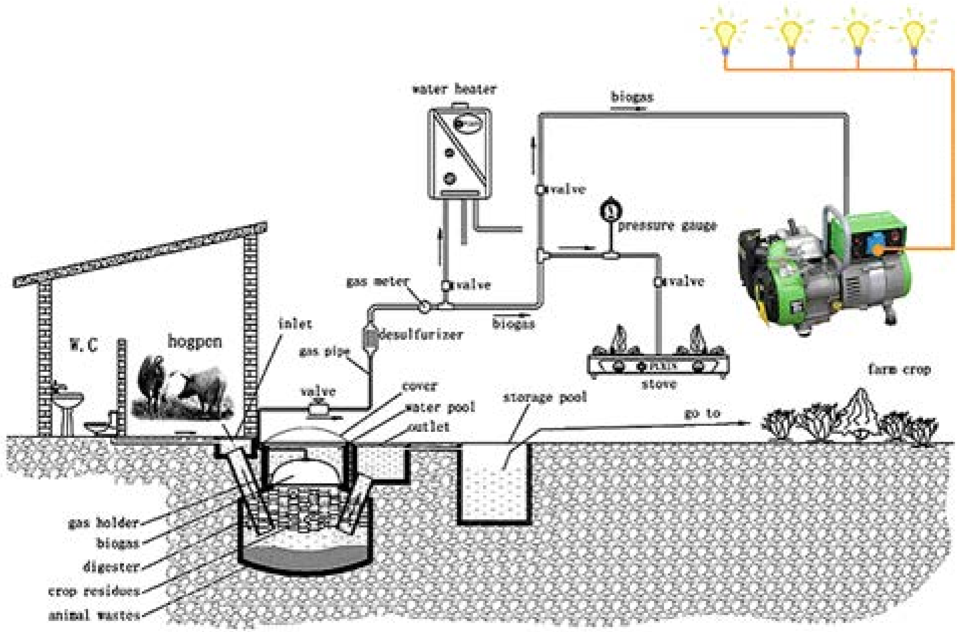
Rural Household Systems



Source: *http://www.drylandfarming.org/*



Source: *www.paceproject.net/*



Source: *https://energypedia.info/*

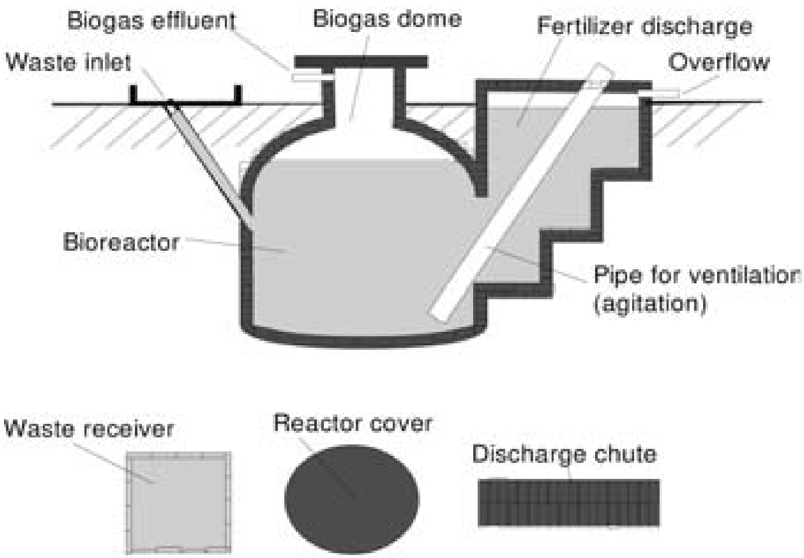
Biogas Stoves and Lamps

Several models of biogas stoves and lamps in display in Tanzania

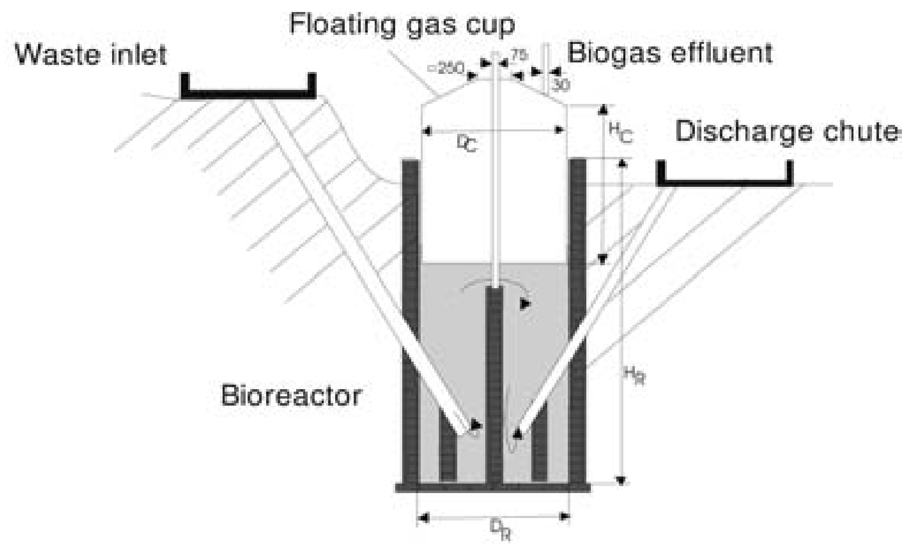
Biogas for cooking

Fatchiyah lights the biogas lamp in her living room in East Java, Indonesia

Two Typical Household Digesters



Fixed-dome Chinese design

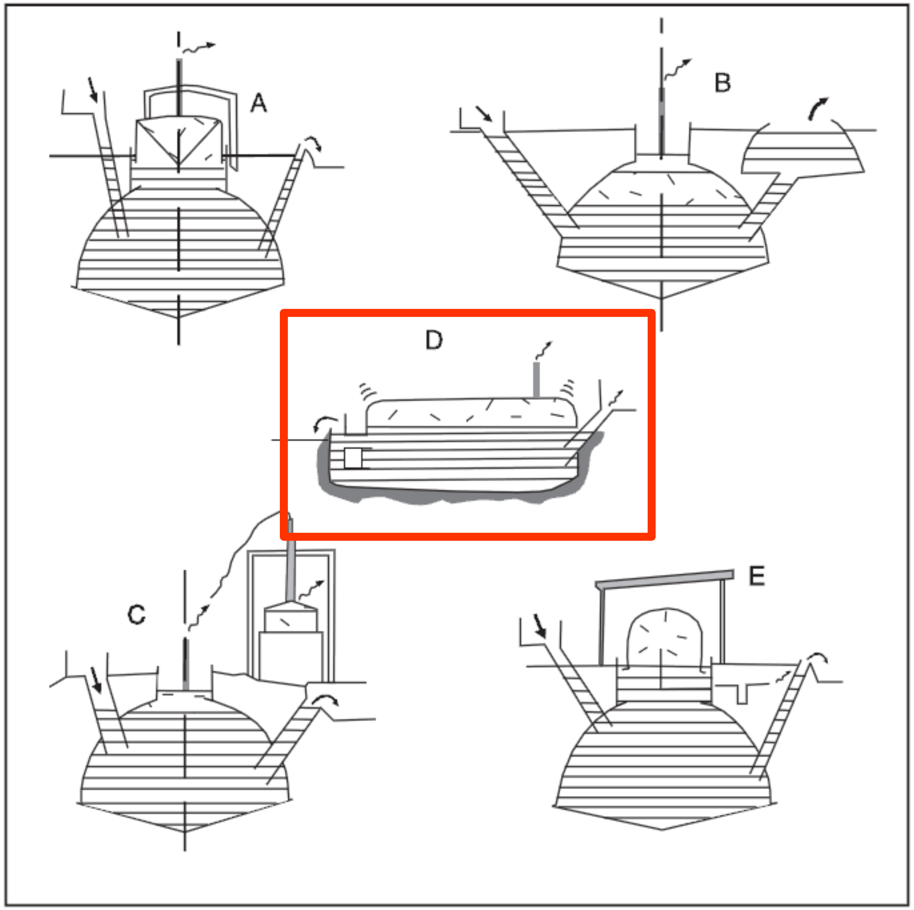


Floating drum Indian design

Typical volume: 4 – 30 m^3

Source: Deublein and Steinhauser, 2008

Other Household Designs



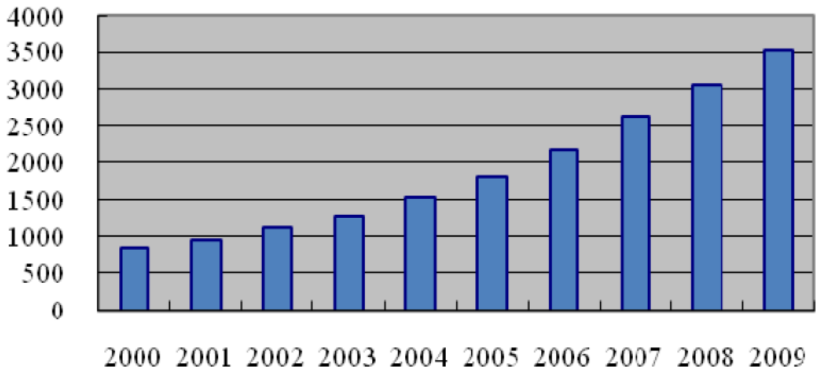
Source: Sasse, 1988

A: Floating-drum;
B: Fixed-dome;
C: Fixed-dome with separate gas holder;
D: Balloon-style;
E: Channel-type with plastic sheeting and sunshade.

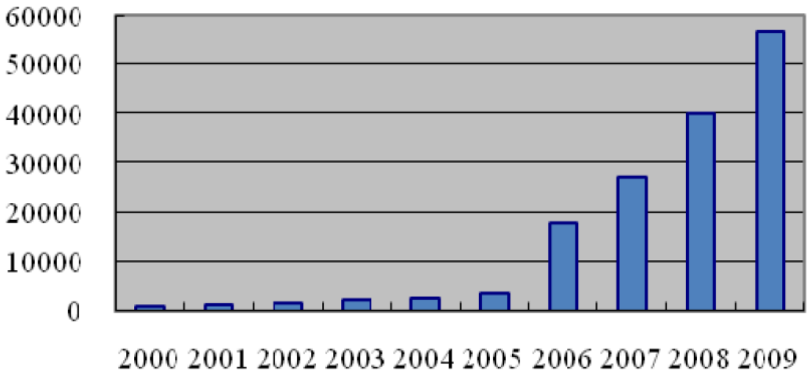
Fixed-dome digester under construction in Kenya

Biogas in China

- Late 1920s: First commercial biogas system
- 1930s: Several systems developed
- 1960s – 1970s: Rapid dissemination
- By 1978: 7 million plants built, but only 3 million working
- 1990s - now: New wave of biogas development



Household digesters (x10,000)



Large digester systems

Charts from: Liu, 2011

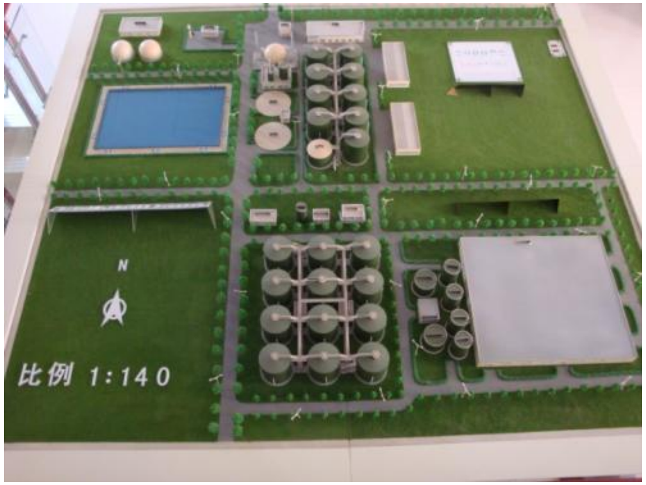
Household Biogas in China

Biogas digester in construction

Commercialized digesters made of reinforced plastic with fiber glass

Source: Zhang Mi, 2007

Farm Biogas Systems in China



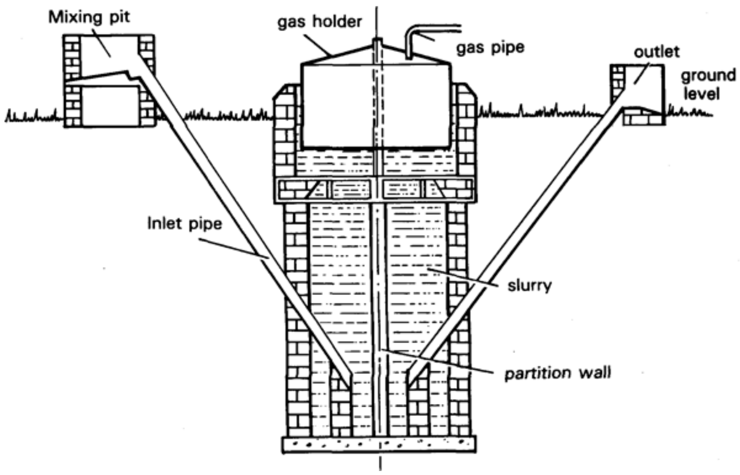
Digesters in two hog farms (above) and a layer hen farm (left) in China in 2013.

Photos: Ni

Biogas in India

- 1897: Mumbai system gas used in lights
- 1907: gas used in an engine
- 1950s – 1970s
  - Developed floating drum design
  - Plants for individual farmers of 7 to 35 m^3 using cattle dung
- 1960s – 1980s
  - Adapted Chinese dome design (4 to 10 m^3)
- 2009: 12 million plants built

Source: David Fulford, n.d.



Floating drum biogas digester design in Indian

Biogas in Nepal

- 1955: Demonstration plant in school
- 1968: Indian (KVIC) plant at exhibition
- 1976: Pilot program of 95 plants used KVIC design with metal gas drums.
- 2009: 189,122 plants built, 98% success rate (highest biogas per inhabitant in the world)

Source: David Fulford, n.d.

Biogas in Nepal

Mrs. Mitha Koirala with her biogas plant, Sarangot near Pokhara.

Mrs. Pria Devi cooks with biogas, Thunilsina, Nepal.

Source: http://www.ashden.org/media/international_photos/2005

Biogas in Africa

- Biogas Technology West Africa Ltd. building sewage systems for hospitals, schools, colleges, etc.
- Underground masonry dome systems 60 to 160 m^3 volume.
- Water recovered and used to flush toilets.
- Gas used for cooking.

- Biogas for hospitals, school etc. in Ghana.

Source: David Fulford, n.d.

Biogas in Rwanda

- Rwanda: Kigali Institute of Science and Technology built sewage systems for overcrowded prisons (10,000 people)
- Underground masonry plants: 100 m^3 volume, linked to make 1,400 m^3.
- Saves 50% of wood for cooking.
- Funding from Red Cross

Biogas plant under construction Kitarama prison, Rwanda.

Prison garden Cyangugu, Rwanda.

Source: David Fulford, n.d.
Source: http://www.ashden.org

Biogas in South America

Digesters on two farms (above) and in an ethanol plant (left) in Guyana in 2012.

Photos: Ni

Biogas Storage

Floating gas holder

Floating drum digester. The drums are lifted for re-paining which allows a view on the double ring wall of the water jacket in a slaughter house in Java, Indonesia.

Source: Sasse, 1998

Digestion Process

Temperature

- Mesophilic: optimally around 30-38 °C, or 20-45 °C
- Thermophilic: 50-55 °C, up to 70 °C
- Fermentation rate doubles at T increase of 10 °C

Solid content

- Normally 5-12% total solid (TS)

Hydraulic retention time (HRT) for animal wastes

- Mesophilic: 20-25 days
- Thermophilic:10-15 days

Most Commonly Used Substrates

- **Animal Wastes**

- **Agro-industrial (food processing) wastes and energy crops**

- **Municipal wastes**

Photos: HEEE

Estimation of Biogas Production

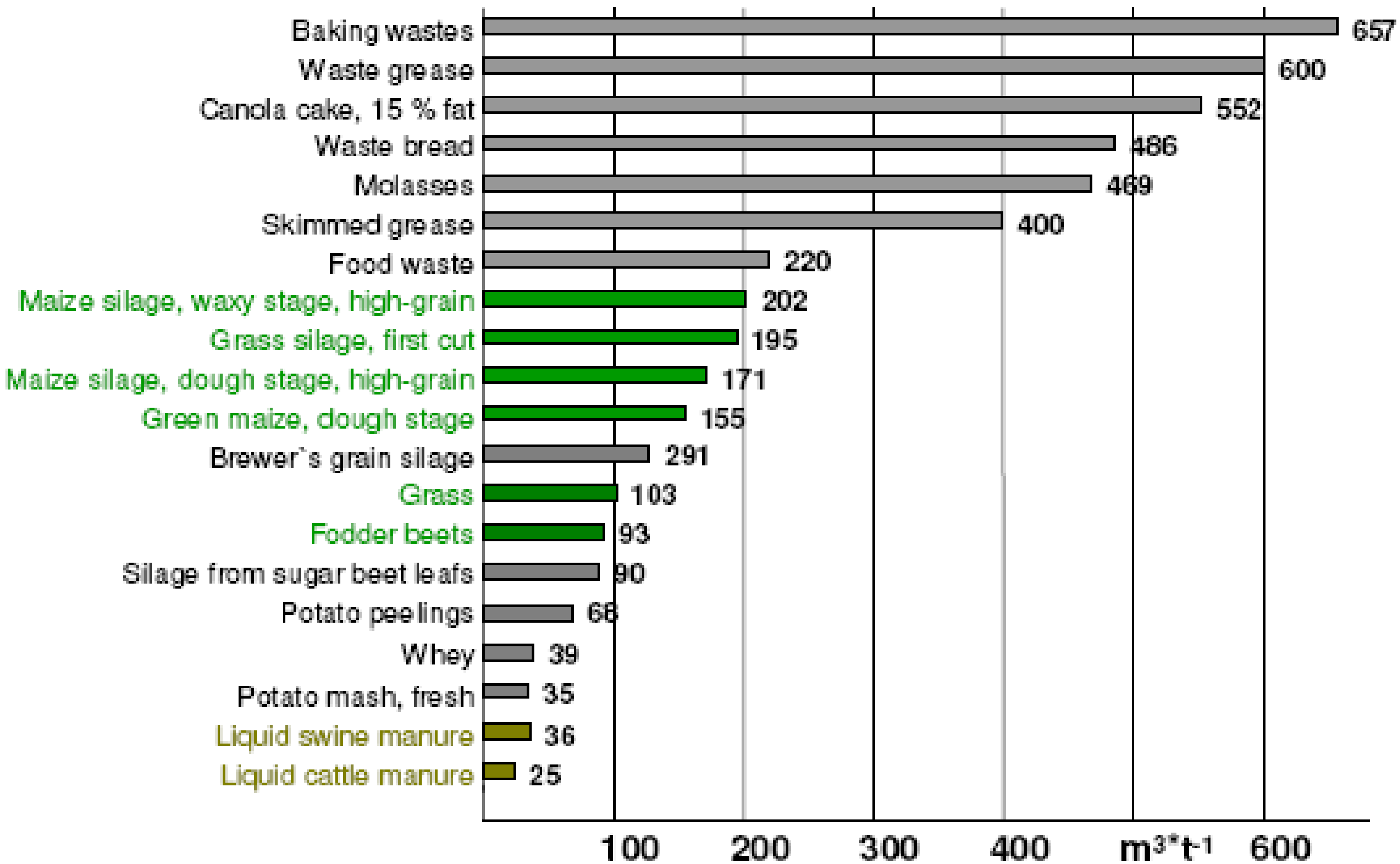
- Based on COD

  1 kg COD = ~ 0.35 m^3 methane

- Based on total solid (TS)

Manure	TS, %	Biogas production		CH_4, %
		m^3/t manure	m^3/t TS	
Cow	18~20	40~50	210~300	60
Hog	20~25	55~65	270~450	60
Poultry	30~32	70~90	250~450	60

More Data for Biogas Yields



Source: Mathias Effenberger, 2006; Curts, 2009

Biogas Yields from Energy Crops

Crop	Crop yield[1)] t DS. ha^{-1}	Measured methane yield[2)] $m^3.t^{-1}$ VS	Calculated methane yield[3)] $m^3 . ha^{-1}$
Maize (whole crop)	9–30	205–450	1,660–12,150
Wheat (grain)	3.6–11.75	384–426	1,244–4,505
Oats (grain)	4.1–12.4	250–365	922–4,073
Rye (grain)	2.1	283–492	535–930
Barley	3.6–4.1	353–658	1,144–2,428
Triticale	3.3–11.9	337–555	1,000–5,944
Sorghum	8–25	295–372	2,124–8,370
Grass	10–15	298–467	2,682–6,305
Red clover	5–19	300–350	1,350–5,985
Alfalfa	7.5–16.5	340–500	2,295–7,425
Sudan grass	10–20	213–303	1,917–5,454
Reed Canary Grass	5–11	340–430	1,530–4,257
Hemp	8–16	355–409	2,556–5890
Flax	5.5–12.5	212	1,049–2,385

Crop	Crop yield[1)] t DS. ha^{-1}	Measured methane yield[2)] $m^3.t^{-1}$ VS	Calculated methane yield[3)] $m^3 . ha^{-1}$
Nettle	5.6–10	120–420	605–3,780
Ryegrass	7.4–15	390–410	2,597– 5,535
Miscanthus	8–25	179–218	1,289–4,905
Sunflower	6–8	154–400	832–2,880
Oilseed rape	2.5–7.8	240–340	540–2,387
Jerusalem artichoke	9–16	300–370	2,430–5,328
Peas	3.7–4.7	390	1,299–1,650
Rhubarb	2–4	320–490	576–1,764
Turnip	5–7.5	314	1,413–2,120
Kale	6–45	240–334	1,296–13,527
Potatoes	10.7–50	276–400	2,658–18,000
Sugar beet	9.2–18.4	236–381	1954–6309
Fodder beet	11.2–20.8	420–500	4233–9360

Source: Murphy et al., 2011

THANK YOU!