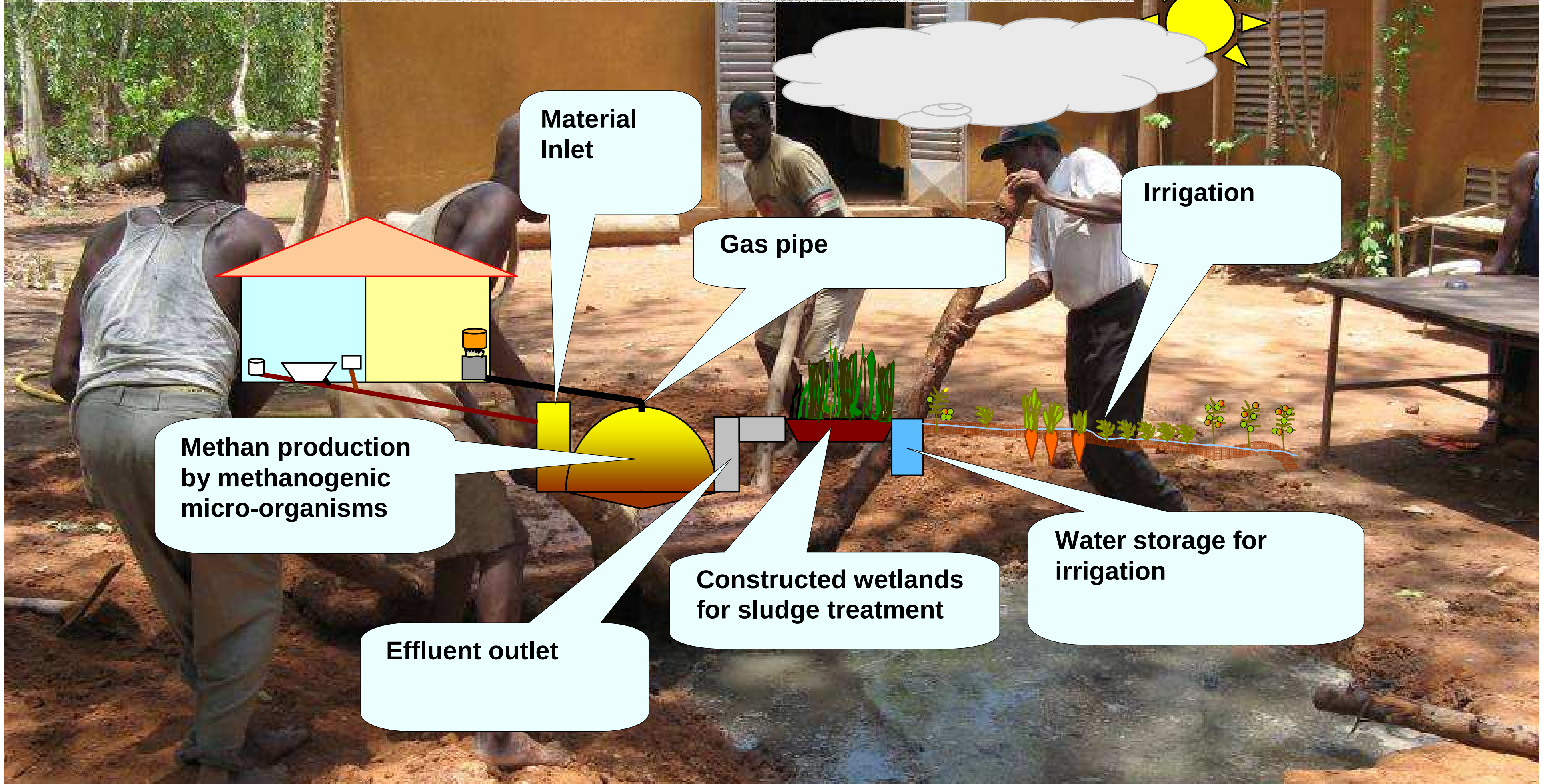
Biogas systems
for wastewater treatment



Biodigestor replacing septic tank. Waste water and domestic waste are treated and transformed into biogas, sludge et water.
Advantages: no work requested to empty septic tanks, waste reuse for energy, fertilizer, irrigation water, cash flow saving

biogas impacts

- ✓ **Energy**
  - Cooking
  - Lighting
  - Food processing and conservation
  - Saving of energy expenditures
- ✓ **Savings in fuel wood**
  - Environmental protection by reduced deforestation
- ✓ **Sanitation**
  - Controlled treatment and reuse or discharge of wastewater
  - Controlled treatment and reuse or discharge of organic waste
- ✓ **Recycling of sanitation sub-products: organic matter and water**
  - Urban environment improved by parks, flowers, trees
- ✓ **Modernity**
- ✓ **Groundwater and climate protection**

Gas Production potential of various types of dung

Gas Production potential of various types of dung	
Types of dung	**Gas production* per Kg dung (m^3)**
Cattle (cows and buffaloes)	**0.023 - 0.040**
Pig	**0.040 - 0.059**
Poultry (Chickens)	**0.065 - 0.116**
Human	**0.020 - 0.028**
Source: Sustainable Development Department (SD) / FAO - A system approach to biogas technology http://www.fao.org/sd/Egdirect/Egre0022.htm	

* calculated on the basis of their volatile solid content

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Specific biogas yield

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Tabelle 2-2: Spezifischer Biogasertrag und Methangehalt

	Biogasertrag [l/kg oTS]	**Methangehalt [Vol.-%]**
Verdauliches Eiweiß (RP)	600-700	70-75
Verdauliches Fett (RL)	1.000-1.250	68-73
Verdauliche Kohlenhydrate (RF + NfE)	700-800	50-55

Tab. 2.9: Biogasertrag und Methangehalt der organischen Stoffgruppen [WEILAND, 2001]

Stoffgruppe	Biogasertrag		Methangehalt	
	$\left[\frac{Nl}{goTS}\right]$		[Vol.-%]	
	Von	bis	von	bis
Kohlenhydrate	0,7	0,8	50	55
Proteine	0,6	0,7	70	75
Fette	1,0	1,25	68	73

Aus diesen Vorgaben lassen sich nun die organische Trockensubstanz sowie die jeweilige Masse der verdaulichen Stoffgruppen je kg Trockensubstanz errechnen /2-9/:

oTS-Gehalt:
(1000-Rohasche)/10 [% TS]
Verdauliches Eiweiß:
(Rohprotein $\cdot VQ_{RP}$)/1000 [kg/kg TS]
Verdauliches Fett:
(Rohfett $\cdot VQ_{RL}$)/1000 [kg/kg TS]
Verdauliche Kohlenhydrate:
((Rohfaser $\cdot VQ_{RF}$) + (NfE $\cdot VQ_{NfE}$))/1000 [kg/kg TS]

http://www.fnr-server.de/ftp/pdf/literatur/HR_Biogas.pdf

Specific biogas yields (**in Nl/kg VS**)

Example with maize

Die weitere Berechnung soll am Beispiel **Silomais** (Beginn Teigreife, körnerreich) verdeutlicht werden (Tabelle 2-3).

Tabelle 2-3: Silomais, Beginn Teigreife, körnerreich (Bsp.)

TS [%]	Rohasche (RA) [g/kg TS]	Rohprotein (RP) [g/kg TS]	VQ_{RP} [%]	Rohfett (RL) [g/kg TS]	VQ_{RL} [%]	Rohfaser (RF) [g/kg TS]	VQ_{RF} [%]	NfE [g/kg TS]	VQ_{NfE} [%]
29	53	92	57	42	82	185	63	628	78

Daraus errechnet sich:

oTS-Gehalt:

$$(1000 - 53)/10 = \mathbf{94{,}7\ \%\ (TS)}$$

Verdauliches Eiweiß:

$$(92 \cdot 57\%)/1000 = \mathbf{0{,}0524\ kg/kg\ TS}$$

Verdauliches Fett:

$$(42 \cdot 87\%)/1000 = \mathbf{0{,}03654\ kg/kg\ TS}$$

Verdauliche Kohlenhydrate:

$$((185 \cdot 63\%) + (628 \cdot 78\%))/1000 = \mathbf{0{,}606\ kg/kg\ TS}$$

Die Massen der Stoffgruppen je kg oTS errechnen sich daraus wie folgt:

Verdauliches Eiweiß:

$$0{,}0524\ kg/kg\ TS \cdot 94{,}7\ \%\ oTS = \mathbf{0{,}0496\ kg\ oTS}$$

Verdauliches Fett:

$$0{,}0365\ kg/kg\ TS \cdot 94{,}7\ \%\ oTS = \mathbf{0{,}0346\ kg\ oTS}$$

Verdauliche Kohlenhydrate:

$$0{,}606\ kg/kg\ TS \cdot 94{,}7\ \%\ oTS = \mathbf{0{,}574\ kg\ oTS}$$

Die Ergebnisse werden nun mit den Werten aus Tabelle 2-2 multipliziert und man erhält die in Tabelle 2-4 dargestellten Biogas- und Methanausbeuten.

Tabelle 2-4: Biogasausbeute und Methanausbeute von Silomais (Mittelwerte)

	Biogas [l/kg oTS]	Methan [l/kg oTS]
Verdauliches Eiweiß (RP)	34,72	25,2
Verdauliches Fett (RL)	43,25	30,5
Verdauliche Kohlenhydrate (RF + NfE)	453,46	238,1
Summe [je kg oTS]	531,43	293,8

http://www.fnr-server.de/ftp/pdf/literatur/HR_Biogas.pdf

Specific biogas yields (**in Nl/kg VS**)

Easy way to go is to:

- **Monitore biogas production during a (batch) experimentation**
- **Determine parameter such as VS of the input and of the output**

$$V_{spe.}\ (\textbf{in l/kg VS}) = V_{biogas}\ (\textbf{in l}) : (VS_{input} - VS_{output}\ (\textbf{in kg})$$

Specific biogas yields (in l/kg VS)

Another easy way to go is to:

- **Umrechnung von oTR (VS) in Biogas ist auch möglich, wenn man die Zusammensetzung des Biogases kennt.**
  - **z.B. hat Biogas mit 60 % Methan + 40 % Kohlendioxid im Normzustand ein spez. Gewicht von 1,214 g/l**

D.h. pro aus 1,214 g VS entsteht 1 l Biogas

$$V_{Biogas} \text{ (in l)} = VS \text{ (in g)} / 1{,}214 \text{ (in g/l)}$$

Potential methan yields from COD

COD_{biogas} (converted into biogas) **= COD_{input} – COD_{output}**

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

Oxydation of 1 mole (22,4 L) CH_4 needs 2 moles O_2 (64g)

- **1g CSB = 0,35 (22,4:64) Nl* (CH_4).**

V_{CH4} (in l) = COD_{biogas} (in g) X 0.35 **(in Nl/g COD)**

Nl = Normliter

1 Nl = 1l, at standard conditions (Temp. = 0℃ and Pr es. = 1 atm)

Cost estimation of biogas plants

Biogas options in Burkina Faso*

Input material[a]	2 cattle + 7 persons	6 cattle + 7 persons	12 cattle + 7 persons
Digester volume	6 m³	6 m³	10 m³
Gas storage	0.7 m³	0.7 m³	1.2 m³
Gas utilisation	1 gas stove : 3 h/d	1 gas stove : 3 h/d	1 gas stove : 6 h/d
	1 gas lamp: 2 h/d	1 gas lamp: 2 h/d	1 gas lamp: 4 h/d
	--	1 permanent 80 to 120l-gas refrigerator	1 permanent 80 to 120l-gas refrigerator
Price[b]	450,000 FCFA (700 €)	450,000 FCFA (700 €)	650,000 FCFA (1000 €)
Saving / benefits[c]	fuel wood: 2.1 t/y	fuel wood: 2.1 t/y	fuel wood: 4.2 t/y
	charcoal: 0.3 t/y	charcoal: 0.3 t/y	charcoal: 0.6 t/y
	petrol, kerosene, lamp oil: 13 l/y (lighting)	petrol, kerosene, lamp oil: 13 l/y (lighting)	petrol, kerosene, lamp oil: 26 l/y (lighting)
	--	bottled gas (LPG): 64 kg/y (= 5.3 btl of 12 kg/y)	bottled gas (LPG): 64 kg/y (= 5.3 btl of 12 kg/y)

[a]: dung from cattle and domestic waste (water) from human activities
[b]: cost estimation of the biogas plans, including costs for construction, plumber work, gas appliances (without refrigerator), work and transport, etc.
[C]: these saving aspect are considered in the case where the produced biogas is used dung from cattle and domestic waste (water) from human activities
* Source: GTZ (2007) - Feasibility Study for a National Domestic Biogas Programme Burkina Faso

One person produces appr. 100–200 g of faeces per day, the dry matter content of which is about 20% (up to 30%).

Source: Sirkka Malkki (--) - Human faeces as a resource in agriculture
http://orgprints.org/8477/01/njf4.pdf

Human faeces characteristics

Volume ($l*pers^{-1}*day^{-1}$)	0,15
N ($g*pers^{-1}*day^{-1}$)	1,5
P ($g*pers^{-1}*day^{-1}$)	0,5
Volume ($l*pers^{-1}*year^{-1}$)	56
N ($kg*pers^{-1}*year^{-1}$)	0,6
P ($kg*pers^{-1}*year^{-1}$)	0,2
N-conc (mg/l)	9 811
P-conc.,(mg/l)	3 270
N/P-ratio	*3*
Notes	High pathogen content. High dry mass.

In terms of biogas production, 1000 persons are needed to have the same amount of biogas, as with 200 pigs, which uses to be the probability border

Source: Folke Günther (2006) – Faeces:
http://www.holon.se/folke/kurs/Distans/Ekofys/Recirk/Eng/fekalier_en.shtml

Average composition of animal dung

Composition	Value
Organic	90%
Nitrogen	1.23%
Phosphoric Acid	0.50%
Potash	0.73%

Composition	Value
Moisture contents	82.84%
Solid contents	16-18%
Volatile solid contents	80.91%
Carbohydrates	30.45%
Cellulose	16.25%
Nitrogen	1.15%

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Comparison of calorific values of different fuel gases

Gas	Calorific value (Joules cm^{-3} - MJ/m^3)
Methane	33.2 - 39.6
Biogas	20.0 - 26.0
Natural gas	38.9 - 81.4
Propane	81.4 - 96.2
Butane	107.3 - 125.8

Adapted from: Meynell, 1972; Natverkstan, 1999

Volumes of other fuels equivalent to $1m^3$ (1000 L) of biogas *(5500 kcal)*

Fuel	Volume (L)
Diesel	0.62
Petrol (gasoline)	0.70
Liquid butane	0.87
Natural gas	0.57

Adapted from: Meynell, 1972; Natverkstan, 1999

Source: Francisco X. Aguilar (2001) - POLYETHYLENE BIODIGESTERS (PBD): *Production of biogas and organic fertilizer from animal manure* http://www.aidg.net/index.php?option=com_remository&Itemid=34&func=download&filecatid=26

Table 1. Daily biogas production per person from human faeces.

Persons No.	1
Wet mass (kg)	0.12
Dry matter mass (kg)	0.035
Organic matter mass (kg)	0.030
Biogas (mol)	0.58
Biogas volume (l)	12.99
Methane (mol)	0.377
Methane volume (l)	8.445
Carbon dioxide (mol)	0.203
Carbon dioxide volume (l)	4.547

Volumes are calculated at standard conditions, (1 atm, 0 °C); under these conditions 1 mol of gas occupies a volume of 22.4 litres.

Source : Tiziana Pipoli (2005) - Feasibility of Biomass-Based Fuel Cells for Manned Space Exploration http://www.esa.int/gsp/ACT/doc/POW/ACT-RPR-NRG-2005-ESPC-Feasibility%20of%20Biomass%20based%20Fuel%20Cells.pdf

VS in faeces: 83 to 91 % , average 87%

RM HPTC Biogas Plant in Brief

HPTC – High Performance, Temperature Controlled

Applications at	Boarding schools, school kitchens Villages Restaurants
Products	Cooking gas for households or big kitchens for schools or orphan homesor similar applications Electricity: The biogas can be used in a genset to replace up to 80% of the diesel to produce electricity. Bio-Fertilizer: The digested feedstock is after the digestion a highly valuable fertilizer.
Feedstock	Gras, Sorghum, Market waste Agricultural waste, Food processing waste Fish waste Kitchen waste Oil press cake 
System	Two-stage digestion system with 1) Hydrolysis and acidification 2) Methanisation
Performance	10-15 times higher than the manure biogas plants due to 1) temperature control 2) hydrolysis and acidification 3) high calorific feedstock
Digester volume	25 m^3
Biogas production	Ca. 60 m^3 per day (20 m^3 net digester volume x 3 m^3 biogas per m^3 digestion volume per day) Methane content: 55-60% 60 m^3 biogas x 60% =36 m^3 methane. Equivalent to 26 kg LPG or 90 kg wood (100% dry) or 36 litre diesel
Temperature	Controlled temperature, 37°C, insulation and solar heating system
Digester/Biogas bag material	Plastic bags with a 3 layer material
Safety devices	"Flame arrester" for blocking fire backstroke "Overpressure Valve" for regulating the gas pressure in the gas system "Solenoid valve" for blocking the gas flow to the genset while not producing electricity
Installation time	7 days

Daily Feeding Rate

The table shows the feeding rate of the feedstock for the daily maximum biogas production of 60 m³ biogas per day. The biogas has a methane content of 60% and this results in a daily methane production of 36 m³.

Feedstock	Feeding rate	Dry Matter	Volatile Solids	Biogas	Methane yield per day
	kg/day	%	%	m³ CH_4/kg VS	m³ CH_4
cattle manure (liquid)	1030	8	80	0,55	36
cattle manure (solid)	330	25	80	0,55	36
Grass (fresh)	470	21,1	91	0,4	36
Market waste	400	25	90	0,4	36
Vegetable waste/market waste	400	25	90	0,4	36
Fish processing waste	270	30	90	0,5	36
Food waste (from canteen kitchen)	185	40	98	0,5	36
Park and garden waste (fresh)	175	42	97	0,5	36
Organic waste (domestic)	90	75	90	0,6	36
Oil seed residue (pressed)	65	92	97	0,62	36

Source: Figures KTBL, own calculation

One m³ of methane has an energy content of 10 kWh; this is the same as 1 litre diesel or 1 m³ natural gas.

The maximum dailys biogas production can replace

- 26 kg LPG (liquified petroleum gas) or
- 36 litres diesel or
- 90 kg of wood (100 % dry)