Sustainable Wastewater Disposal Solutions

designing a world of hope

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Engineering Ministries International

Course Description

Engineers and architects who are going to design in the Majority World need to understand that there are sustainable waste disposal solutions available. Since these techniques may not be cost effective in a developed country, most engineers and architects have limited knowledge of their benefits. Those who are taking this course will learn about the sustainable design of composting toilets and the use of urine through a case study of biodigesters in Cambodia. **To best serve those in the Majority World, EMI volunteers need to be equipped with a wide range of sustainable design solutions.**

Learning Objectives

1. Understand how good sanitation in the Majority World improves the health of a building's inhabitants and the environment.
2. Recognize that the disposal and treatment methods of human waste implemented in developed countries may not be feasible in the Majority World and design appropriate systems to utilize local solutions and resources.
3. Explain how sustainable disposal methods can be used in the Majority World through simple waste treatment systems.
4. Discover that human waste is an adaptive resource, which includes fertilizer for plants and gas generation.

Education:

- University of Anchorage Alaska, BSCE, 1986
- University of Denver, Master of Applied Science, Environmental Policy & Management (Energy & Sustainability), 2011

Employment:

- Over 30 years as a consulting engineer in the fields of project management, design, construction management, surveying, and construction observation
- WithersRavenel in North Carolina: Vice President, Director – Utilities

Certifications:

- LEED AP
- NASSCO (Pipes, Manholes, and Cured-in-Place-Pipe)
- Samaritan Purse DART training (in the past)

Author:

Paper Money Messages
*Vol 1 – Global
*Vol 2 – Notgeld
*Vol 3 – Christianity

Jeff's EMI Experience

- Zaire, Africa, 1994: School, master planning and surveying
- Kenya, Africa, 1994: Library, surveying
- Bangladesh, 1997: Hospital, surveying and mapping utilities
- Haiti, 1999: Orphanage, surveying
- India, 2000: Schools and homes for elderly pastors, surveying
- Ukraine, 2001: Handicap orphanage, surveying
- Cambodia, 2002: School for girls, surveying and water/wastewater
- Mozambique, Africa 2003: Master planning, surveying and water/wastewater
- Bolivia, 2005: Christian University, surveying and water/wastewater
- Liberia, Africa 2006: Church, master planning, surveying and water/wastewater
- China, 2008: Assistant team leader, surveying and water/wastewater
- Haiti, 2009: Orphanage, master planning, surveying and water/wastewater
- Cambodia, 2012–2017: TransformAsia – David's Center Orphanage, Biodigester and Biosandfilter

Served as a Representative in North Carolina

Helping the Environment and Protecting Our World

Happy Times – Channa Reunion!

Sad Times – Stey Nee's Last Days of Life

Cambodia Orphanage David's Center 2015

Presentation Outline

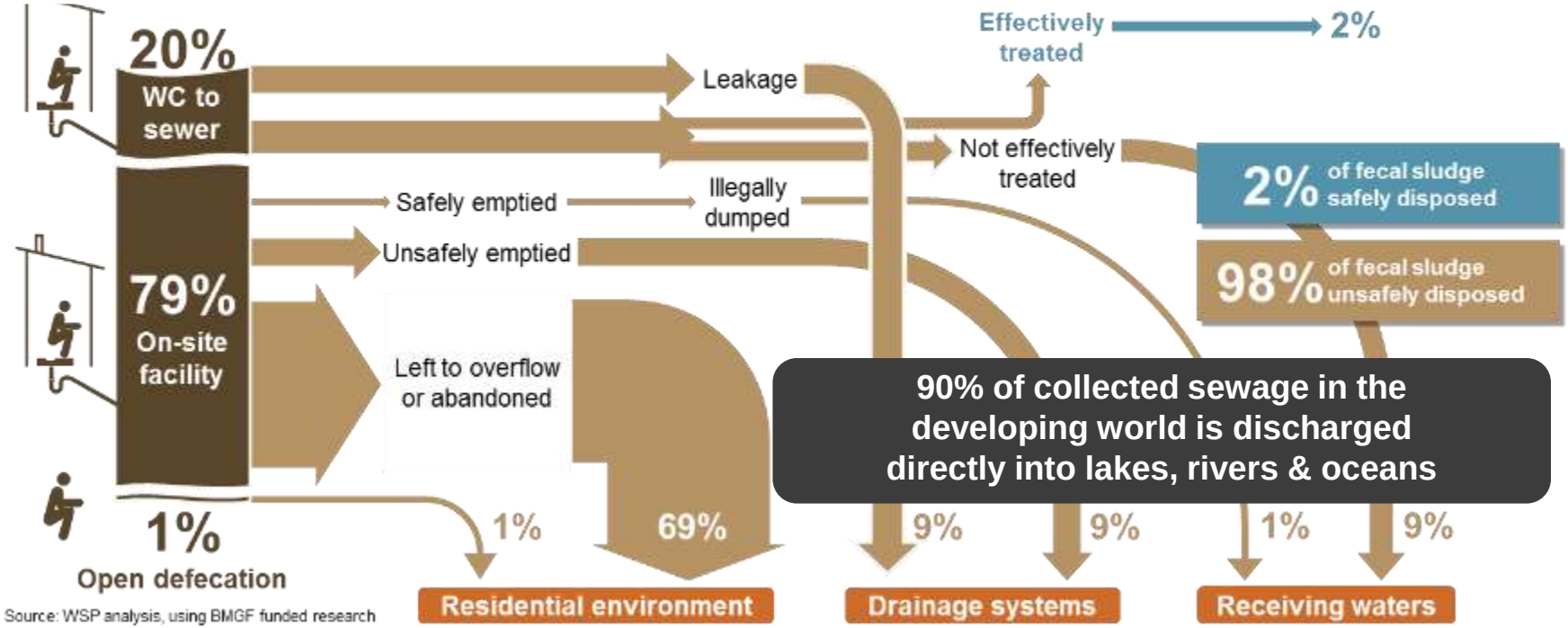
I. Sanitation/Bacteria Discussion

II. Developed World Wastewater Design Compared to Majority World

III. Type of Wastewater Disposal
- Septic Tank/Leach Field
- Pour Flush
- Composting Toilets (benefits of compost)
  Urine Separation, Compost, and C/N Discussion
- Biodigesters

IV. Questions/Discussions

A toilet is only part of the sustainable solution!



Dhaka, Bangladesh

"Global market opportunity for reinvented toilets," Haley Hill, July 20, 2015

Long-term sanitation for all!

Disposal of untreated waste
and impact to the environment

World Resources

The developed countries and ***EMI typical design (septic tank/leach field)*** **wastewater solution** takes three potentially valuable resources (fecal matter, urine, and water) and mixes them into one product that becomes a waste product that must be treated and disposed, which utilizes a lot of resources.

Although it is not a western world practice, it is very beneficial to separate the **grey water** (sink, shower, etc.) from the **black water** to simplify treatment.

Wastewater

Sewage can include waste from many sources—industries, hospitals, garages, etc. **This presentation uses the term "waste" or "wastewater," which is strictly human or animal fecal material and urine.**

<u>Detergents</u> including soap, antibiotics, etc. inhibit the activities of methane-producing bacteria, and the addition of these substances in the system must be avoided.

The Majority World often makes use of “waste”

Manure patties for cooking/heating

Let’s view “waste” as a resource and realize that there are other views in the world.

http://www.hardrainproject.com/hrpl?n=6483

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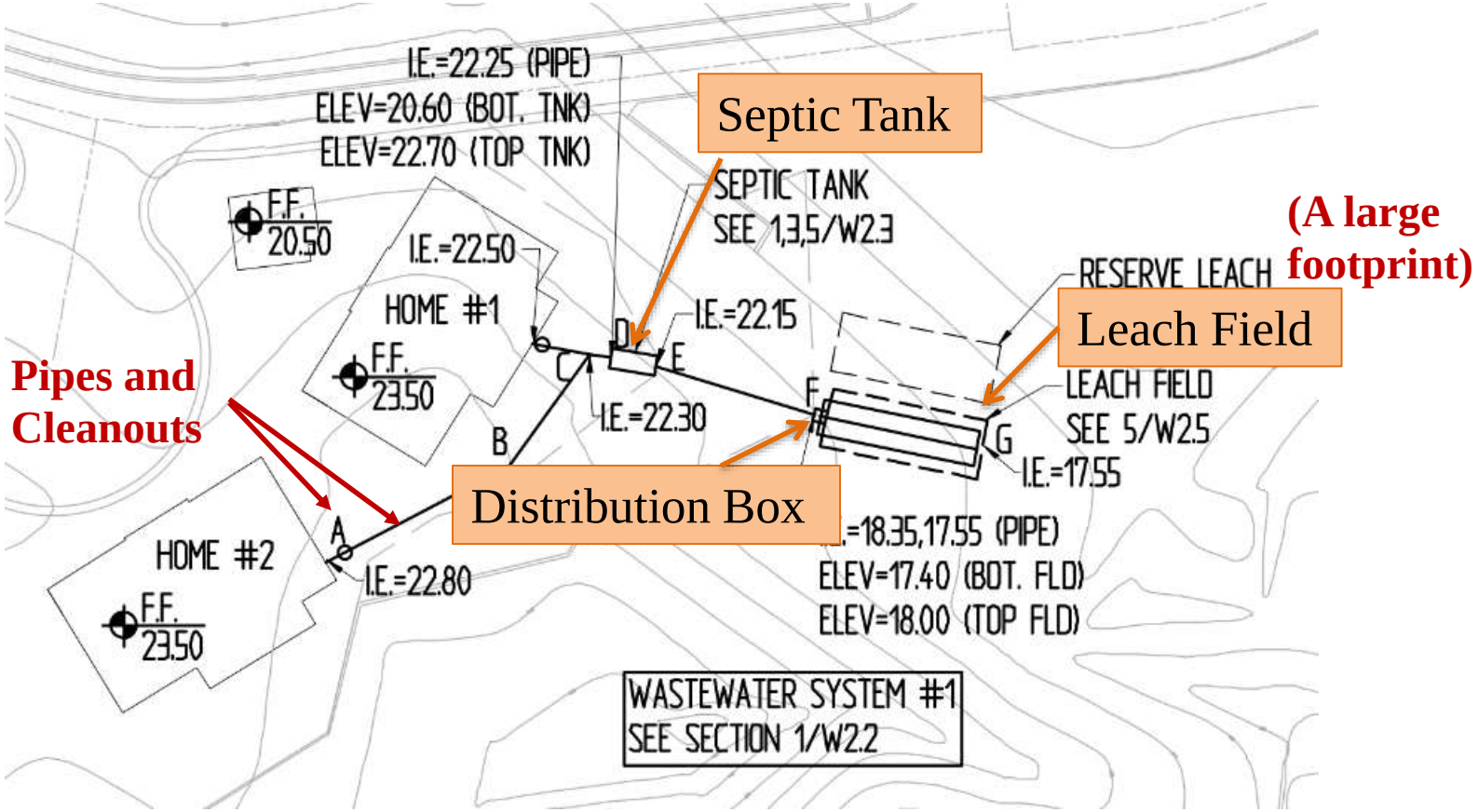
Traditional Developed Country Rural Design Septic Tank/Leach Field

Major components are a septic tank, distribution box, and leach field.



Septic Tanks/Leach Fields

Although septic tanks can be beneficial, there are other issues that EMI volunteers should consider before selecting a septic tank and leach field system as the final design solution. Name a few?

- What is the percolation rate of the soil?
- Is there rock?
- What is the height of the ground water?
- Is there a well or waterbody nearby?
- Is there enough area for the leach field (including reserve area)
- What is the topography of the site?
- Is it possible to have more than one type of system? System for western visitors and a system for locals?
- Is there a need for **compost** (fertilizer) or energy (**biogas**)?

Pour Flush (Two Types)

Raised floor with lower drain = good design

Benefits: Uses a small amount of water (less than ½ of a flushing toilet) and has very simple maintenance.

A standard flushing toilet can leak water, which is difficult to detect.

Composting Toilet

Conserves Water and Generates Quality Soil

Use of Toilet

After each use of the latrine, add 1–2 cups of a dry organic material to cover any fresh excrement.

Ideally urine should be separated.

Examples of these dry materials are sawdust, dry leaves, dry grass, or wood ash. Also, cover the opening after finishing. Any spots on the pile that appear wet should be covered with dry material.

What are the advantages of a Composting Toilets?

http://commons.wikimedia.org/wiki/File:Sawdust_composting_toilet.jpg

Composting Toilet – Advantages

- Does not require a source of water, so it is technologically appropriate for water-scarce areas.
- It is odorless and does not attract insects or flies when properly maintained.
- The composting latrine can be built in locations where other latrines cannot, such as areas of rock, in floodplains, in areas with a high groundwater table, and areas close to surface water.
- It does not need to be moved or rebuilt since the compost is regularly emptied, which extends the life of the latrine.
- Compost is a useful resource.
- Urine (if separated) is also a useful resource.

Jenkins, Joseph. 2005

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Composting Toilet – Urine Separation

Two Main Reasons for Urine Separation:

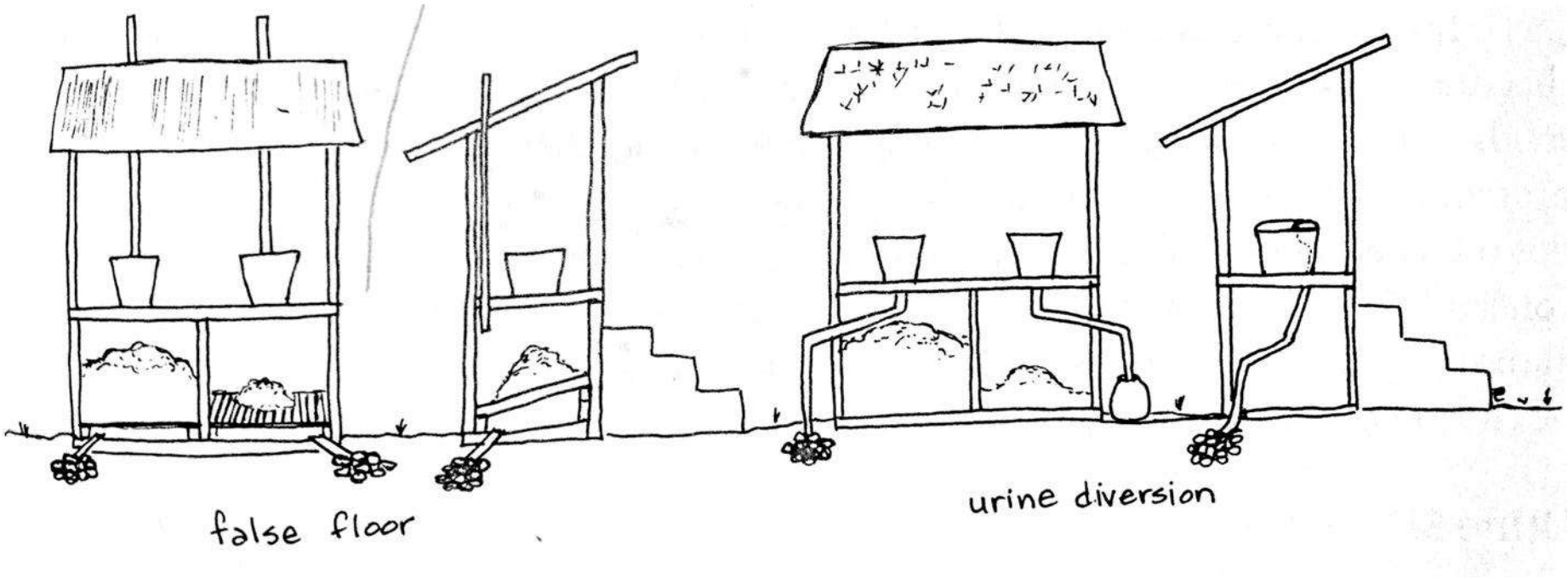
1. Adverse effects on the compost pile:
   - Reduces the transfer of oxygen in the compost pile.
   - Urine has a high nitrogen content *(C/N ratio is 0.8:1, which is below optimal C/N Ratio of 30:1)*
2. Urine is a resource. High nitrogen and phosphorus is a valuable source of nutrients for agriculture.

Use of Urine

- When storing urine, seal the container to reduce loss of nitrogen through the conversion of ammonia to nitrogen gas (Mihelcic et al 2009)
- Dilute urine before applying it to the fields. (typ. 1 part urine to 4 parts water)

Jenkins, Joseph. 2005
(Unless otherwise noted)

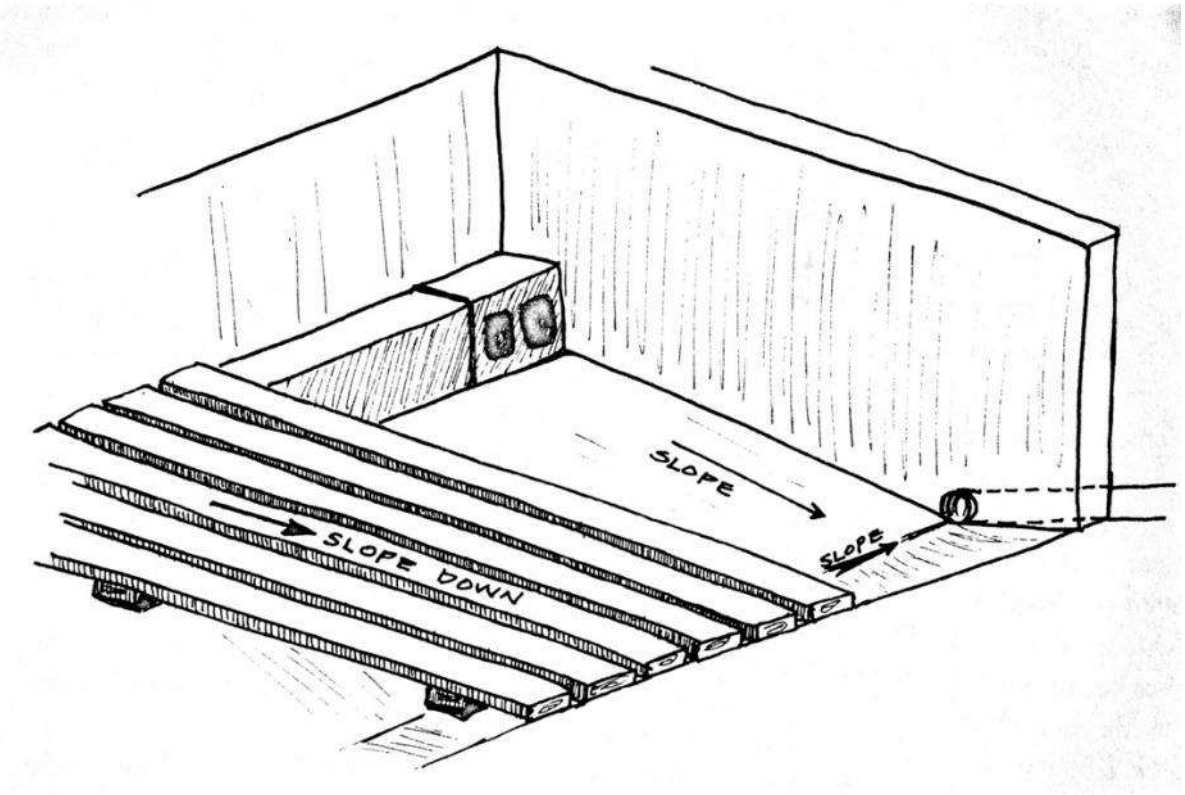
Composting Toilet – Urine Separation



This design uses one side at a time to allow the other side to compost

Mihelcic, J, L. Fry, E. Myre, L. Phillips and B. Barkdoll. 2009.

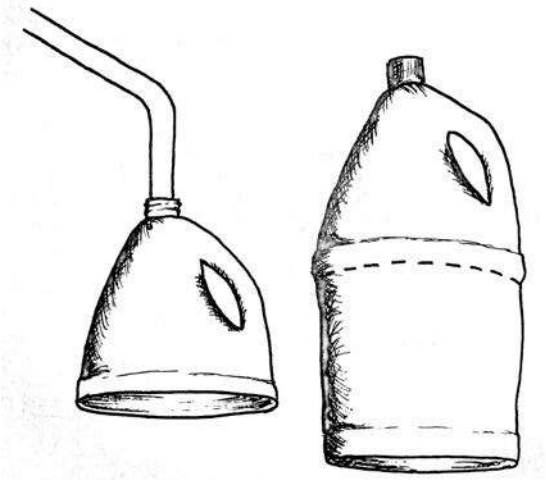
Urine Separation – False Floor



A false floor is a non-intrusive design

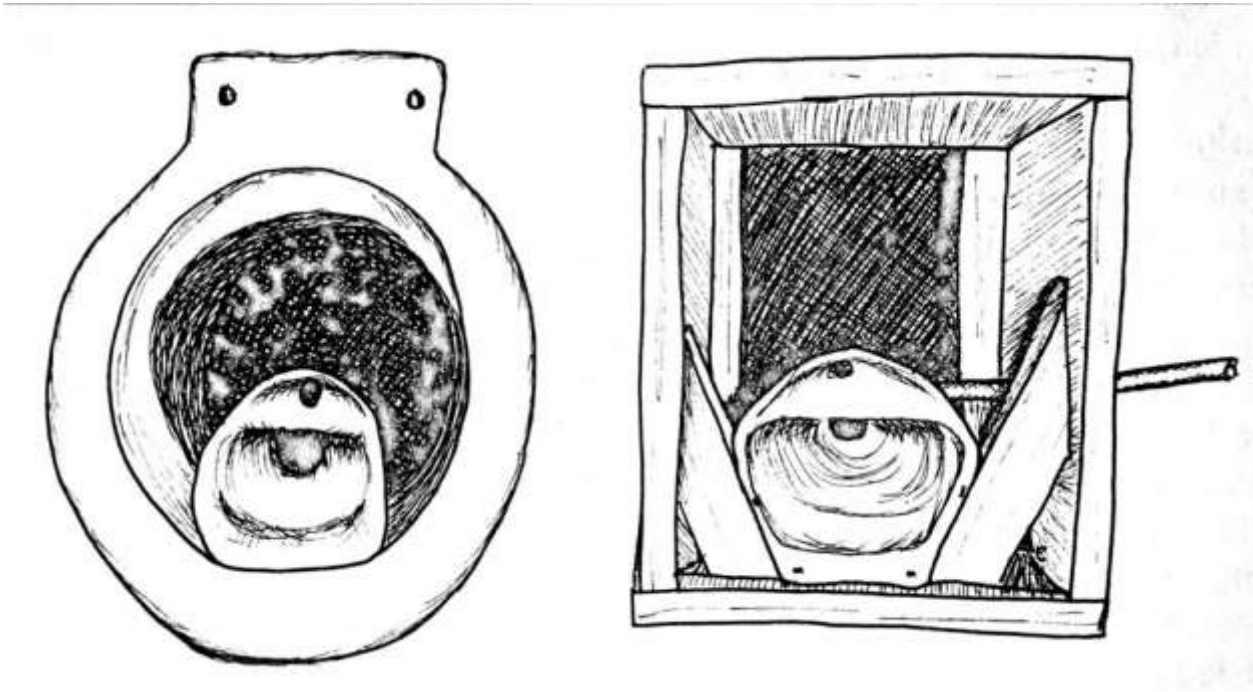
Mihelcic, J, L. Fry, E. Myre, L. Phillips and B. Barkdoll. 2009.

Urine Separation – Diversion Method



Innovative use of a plastic bottle

To Produce



Can be incorporated into an existing system

Mihelcic, J, L. Fry, E. Myre, L. Phillips and B. Barkdoll. 2009.

Urine Separation – Diversion Method

Wing 2012. Cambodia TransformAsia

Urinals for Males

www.googleimages.com

Compost Advantages

Name a few…

- It has a greater fertilization value than raw farmyard manure because nitrogen is available in a form that can be immediately absorbed (National Biodigester Programme 2011c)
- Holds water better
- Repels termites—raw dung attracts termites, which can harm plants
- Reduces weed growth by about 50%
- Compost also adds slow-release nutrients essential for plant growth
- Creates air spaces in soil
- Helps balance the soil pH

Jenkins, Joseph. 2005
(Unless otherwise noted)

Is Western Design Sustainable?

Majority World design needs to be different than Western design.

Energy and materials are abundant and inexpensive in the developed world.

Methane flaring to reduce greenhouse gas (treated as a waste product)

Key Consideration: Does designing to current U.S. standards offer a sustainable solution?

http://www.nytimes.com/2011/09/27/

Sustainability Issues

Cambodian village

"Waste, waste everywhere" or untapped resources?

Consider environmental and health consequences associated with the production of charcoal?

Wing 2013. Cambodia TransformAsia

C/N Ratio

The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon/Nitrogen (C/N) ratio.

Optimal C/N Ratio for a Compost Pile: 30:1

A C/N ratio ranging from 20:1 to 30:1 is considered optimum for anaerobic digestion.

If the C/N ratio is out of range the gas production will be low:

- C/N too high = *nitrogen consumed rapidly by methanogens*
- C/N too low = *results in high PH that kills the methanogen population*

Ref: Tasneem Abbasi, S.M.Tauseef & S.A. Abbasi. 2012

C/N Ratio

Human excreta has a low C/N ratio therefore mixing it with a material that has a high C/N ratio is beneficial.

- Sprinkling sawdust on a compost pile.
- Loading straw at the base of a digester.

Note (**60**+**8**)/2= 34.

Raw Materials	C/N Ratio
Pigs	6
Duck dung	8
Human excreta	**8**
Chicken dung	10
Goat dung	12
Sheep dung	19
Cow/Buffalo dung	**24**
Elephant dung	43
Straw (maize)	**60**
Straw (rice)	70
Straw (wheat)	90
Saw dust	**above 200**

Ref: United States Forces – Afghanistan, Joint Engineering Directorate. 2011

Biodigester Basics

Latrine is plumbed into biodigester—no special effort. *(A concern for some?)*

Inlet must be fed with manure and an equal volume of water.

Model created by the National Biodigester Program

Bio-Slurry

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What is a Biodigester and Biogas?

Biogas is a mixture of methane and carbon dioxide and is produced by the action of bacteria on organic material in airless conditions (anaerobic digestion). This technology is feasible for small household or a project that has around 6 pigs or 3 cows.

An unsustainable alternative—charcoal!

Biodigester – Fixed Dome

Inlet must be fed with manure and an equal volume of water

Outlet to the Compost Area

Elevation of Wastewater Levels

Model: 4 m^3 full scale section

2013 National Biodigester Program, Cambodia Phnom Penh

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Biodigester in Operation

Wing 2016. Cambodia

There are millions of biodigesters in India and Asia.

Night soil *(not recommended)*. This is waste that has not been digested.

Most water resource engineers have never heard of a biodigester.

Biodigester in Operation

Inlet

Outlet

Biodigester Advantages

Biogas systems produce excellent bioslurry that has fewer odors and better nutrient strength for use on a farm. *(Less negative impact to environment like processed fertilizers)*

No flies!

Proof that there is no odor!

Use of Methane – Cooking

Biogas double-burner stove

Secondary lighting

What is a consideration for this type of light?

Solar Use Instead of Biogas

Biodigester Size

The biogas plant size is dependent on the average daily feed stock and hydraulic retention time of the material in the biogas system.

Plant Size		Daily Feedstock		Daily Water	
m^3	***ft^3***	***kilogram***	***pounds***	***liters***	***gal***
4	***106***	***24***	***53***	***24***	***6***
6	***212***	***36***	***79***	***36***	***10***
8	***283***	***48***	***106***	***48***	***13***
10	***353***	***60***	***132***	***60***	***16***
15	***530***	***90***	***198***	***90***	***24***
20	***706***	***120***	***265***	***120***	***32***

Plant size is the sum of digester volume and gas storage based on a hydraulic retention time of 35 days

Ref: United States Forces – Afghanistan, Joint Engineering Directorate. 2011.

Fixed Dome Biodigester Plan

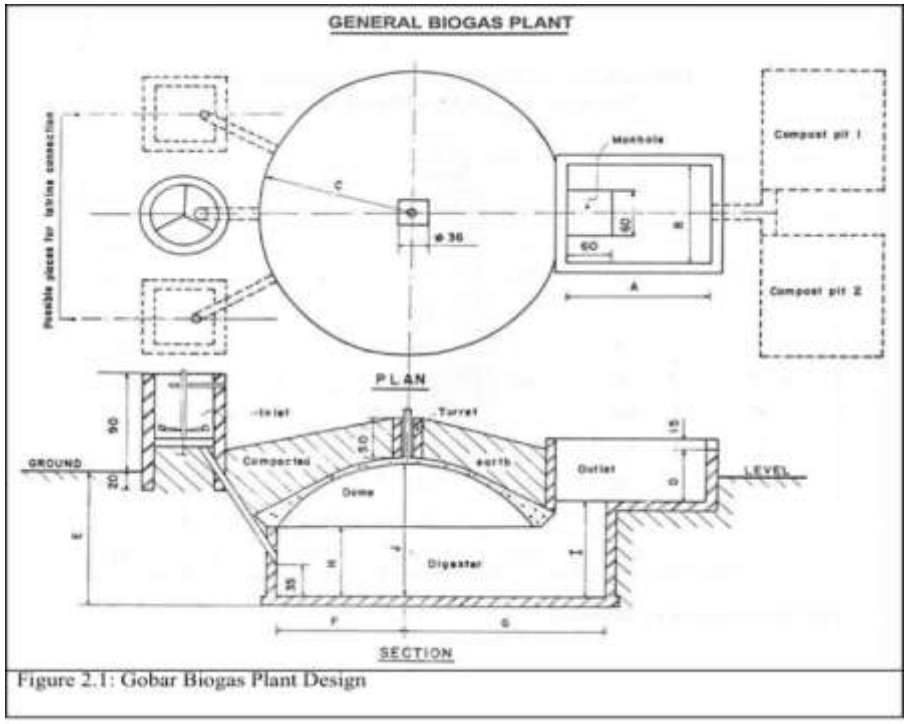


Figure 2.1: Gobar Biogas Plant Design

	Plant Size											
	4 m^2 (141 ft^3)		6 m^2 (212 ft^3)		8 m^2 (283 ft^3)		10 m^2 (353 ft^3)		15 m^2 (530 ft^3)		20 m^2 (706 ft^3)	
	cm	ft	cm	ft	cm	ft	cm	ft	cm	ft	cm	ft
A	140	5	150	5	170	6	180	6	248	8	264	9
B	120	4	120	4	125	4	125	4	130	4	176	6
C	135	4	151	5	170	6	183	6	205	7	233	8
D	50	2	60	2	65	2	68	2	84	3	86	3
E	154	5	155	5	168	6	172	6	180	6	203	7
F	102	3	122	4	135	4	154	5	175	6	199	7
G	195	6	211	7	230	8	243	8	265	9	293	10
H	86	3	92	3	94	3	105	3	115	4	115	4
I	112	4	116	4	124	4	127	4	132	4	137	4
J	151	5	160	5	171	6	175	6	193	6	203	7

Ref: United States Forces – Afghanistan, Joint Engineering Directorate. 2011

Biodigester Cost – Fixed Dome

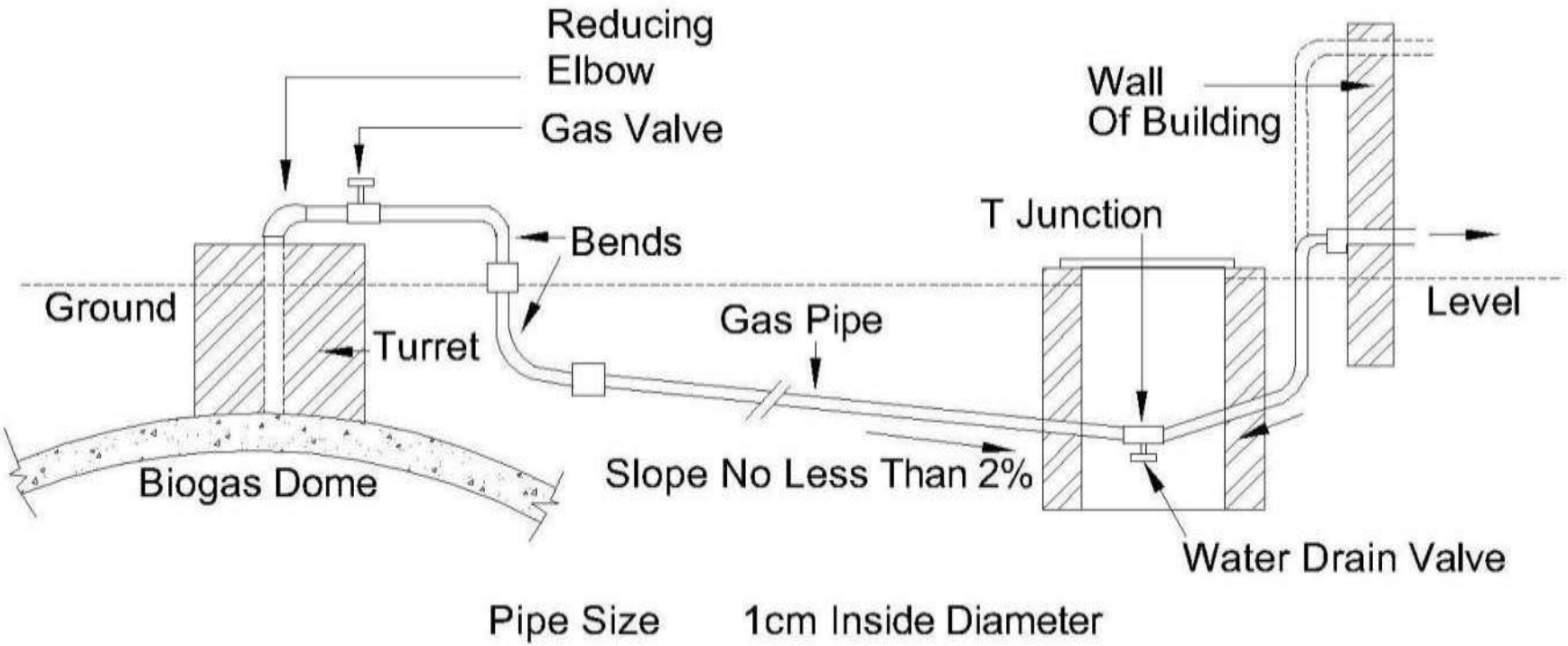
The National Biogester Program of Cambodia offers $150 rebates to homeowners that install a biodigester. The fee includes the following:

- Inlet chamber, dome, outlet structure
- Supervisor
- 2-year warranty

Biodigester Size (m^3)	Total Cost	Use of Biogas Stove Duration (Hr.)	Use of Biogas Lamp Duration (Hr.)
4	$550	2–4	8–6
6	$620	4–6	16–24
8	$720	6–8	24–32
10	$800	8–10	32–40
15	$1,100	10–15	40–60

National Biodigester Program Cambodia 2014

Biodigester – Fixed Dome



Ref: United States Forces – Afghanistan, Joint Engineering Directorate. 2011.

Dome Construction: Brick S-Hook Method

- Wood pole rotated around central nail and upper nail used to measure brick placement.
- The smallest biodigester ($4m^3$) takes about 14 days to construct.

National Biodigester Program Kampot, Cambodia 2013

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Biodigester for a Small Household

The smallest size biodigester in the chart, 4 m^3 (141 ft^3) has a overall length of about 16’ and a depth of 5’.

S-hook counter balance to hold bricks in place

Kampot, Cambodia 2013

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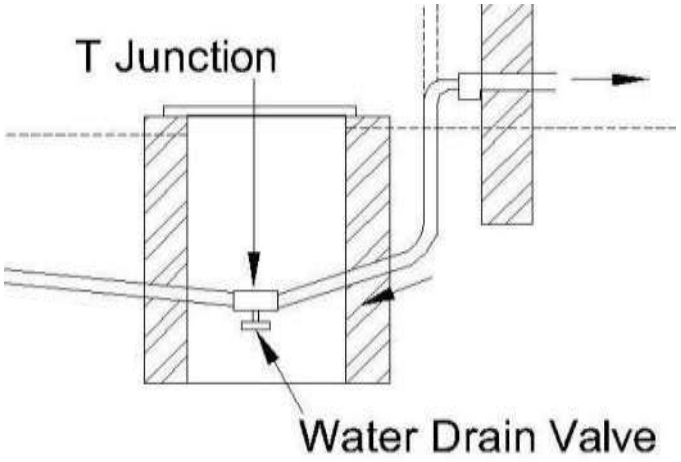
Case Study – Biodigester

After two years of operation, the gas pressure has decreased. The user has put up shields to keep the wind from blowing out the frame from the burner. The type and amount of waste that is being fed to the biodigester has not changed.

What do you think is the issue?

Condensation in the line.



Biodigesters – Challenges

- A biodigester needs to be fed every day
- Requires water to mix with the manure
- Not as suitable for cold climates unless solar is used
- The construction of the dome takes skill
- To a Western designer, there is the appearance that the design is more complicated
- It takes time, roughly 60 days, for the initial biogas to be generated
- Innovative biogesters (plastic bags, steel drums, etc.) often have premature failures that have given biodigesters a bad reputation

Jenkins, Joseph. 2005

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Biodigester – Caution: Many Innovative Designs with Varying Levels of Success

Plastic Bag

Floating Dome

"Water for World" is typically a great design guide, however the floating dome design appears to have many issues.

Conclusion

- Research to find out what has worked in the area! Are there existing organizations/contractors that can build the treatment device?
- There is more to EMI "waste" disposal than simply designing a septic tank and disposal pit (the typical design solution).
- We need to use every available tool in our bag to serve our clients well and constantly seek out sustainable methods. *"When all you have is a hammer, everything looks like a nail."*
- Human and animal excrement is not "waste" but instead a valuable resource that can generate a beneficial fuel.
- We must look beyond our Western culture and engineering experience when finding sustainable solutions.

Questions?

Speaker Contact Information

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References

*Key **Composting** References:*

Jenkins, Joseph. 2005. The Humanure Handbook, 3rd Edition, A Guide to Composting Human Manure. Chelsea Green Publishing.

*Key **Biodigester** References:*

National Biodigester Program. 2015. *http://nbp.org.kh*

Brennan, S. and J. Withgott. 2008. *Environment: The science behind the stories.* 3rd ed. San Francisco, CA: Pearson Benjamin Cummings.

Hill, D. 2006. *Basic microbiology for drinking water personnel.* 2nd ed. Denver, CO: Glacier Publishing Services Inc.

Mihelcic, J, L. Fry, E. Myre, L. Phillips and B. Barkdoll. 2009. *Field guide to environmental engineering for development workers.* Reston, Virginia: American Society of Civil Engineers ASCE.

Tasneem Abbasi, S.M. Tauseef and S.A. Abbasi. 2012. Biogas Energy. Springer New Yourk Dordrecht Heidelberg London.

World Bank. 2010. Cambodia: Supporting self-sustaining commercial markets for improved cookstoves and household biodigesters. http://siteresources.worldbank.org/INTEAPASTAE/Resources/Camb-Web-FINAL.pdf.

World Health Organization. 2004. Water, sanitation and hygine links to health http://www.who.int/water_sanitation_health/publications/facts2004/en/print.html

World Health Organization WHO/UNICEF. 2010. A snapshot of drinking-water and sanitation in the MDG region south-eastern Asia-2010 update. http://www.wssinfo.org/fileadmin/user_upload/resources/128462626359-SEA_snapshot_2010.pdf

Images of innovative biodigesters:

http://www.habmigern2003.info/biogas/Baron-digester/Baron-digester.htm

http://www.sswm.info/category/implementation-tools/wastewater-treatment/hardware/solid-waste/anaerobic-digestion-organic-

References

United States Forces – Afghanistan, Joint Engineering Directorate. April 2011. Biogas Plant Construction Manual. Fixed-dome Digester: 4 to 20 Cubic Meters. Kabul, Afghanistan. Includes the following ten references:

Bajgain, Sundar, Biogas Support Programme (September 1994) “Construction Manual for GGC 2047 Model Biogas Plant”. P.O. Box No. 1966, Kathmandu, Nepal.

Bioenergy Systems Report: "Innovations in Biogas Systems and Technology" (1984). Bio- energy Systems and Technology Project of the USAID.

Chengdu Biogas Research Institute (1989) “The Biogas Technology in China”, Chengdu, China. Karki, A. B. and K. Dixit (1984) "Biogas Fieldbook". Sahayogi Press, Kathmandu, Nepal.

Kariki, A.B. and K. Dixit (1984) “Biogas Fieldbook”. Sahayogi Press, Kathmandu, Nepal.

Karki, A. B., K. M. Gautam and A. Karki (1994) "Biogas Installation from Elephant Dung at Machan Wildlife Resort, Chitwan, Nepal". Biogas Newsletter, Issue No. 45.

Lagrange, B. (1979) "Biomethane 2: Principles - Techniques Utilization". EDISUD, La Calade, 13100 Aix-en-Provence, France.

Lund, M. S., S. S. Andersen and M. Torry-Smith (1996) "Building of a Flexibility Bag Biogas Digester in Tanzania". Student Report. Technical University of Denmark, Copenhagen.

Office of the Leading Group for the Propagation of Marshgas, Sichuan (Szechuan) Province, Peoples Republic of China, Edited: Van Buran, Ariane, “A Chinese Biogas Manual” http://www.fastonline.org/CD3WD_40/JF/432/24-572.pdf (same reference from Biodigester club)

Sustainable Development Department (SD), Food and Agriculture Organization of the United Nations (June 1997), A System Approach to Biogas Technology. Internet: http://www.fao.org/sd/egdirect/EGre0022.htm

Volunteers in Technical Assistance (1980). “3-Cubic Meter Biogas Plant, A Construction Manual”. Arlington, Virginia, USA