

## REFERENCES

- ABDULKAREEM, A. S. 2005. Refining Biogas Produced from Biomass: An Alternative to Cooking Gas. *Leonardo Journal of Sciences*.
- AHRING, B. K. 2003. Perspectives for Anaerobic Digestion. In: SCHEPER, T. (ed.) *Advances in Biochemical Engineering/Biotechnology*. Springer-Verlag Berlin Heidelberg
- AIR-LIQUID-GAS-ENCYCLOPAEDIA. 2009. *Methane, CH<sub>4</sub>, Physical properties, safety, MSDS, enthalpy, material compatibility, gas liquid equilibrium, density, viscosity* [Online]. Available: <http://encyclopedia.airliquide.com>.
- AL-DAHMAN, M. Bio-Energy Production from Anaerobic Digestion of Animal and Farm Wastes. Energy Summit - University of Missouri System, 2009 Missouri S&T.
- ALVAREZ, J. M.-. 2003. Biomethanization of the Organic Fraction of Municipal Solid Wastes.
- ALWIS, A. A. P. 2001. *Study on the potential of biogas in Sri Lanka*, ITDG - South Asia.
- ANGELIDAKI, I., ELLEGAARD, L. & AHRING, B. K. 2003. Applications of the Anaerobic Digestion Process. In: SCHEPER, T. (ed.) *Advances in Biochemical Engineering/Biotechnology*. Springer-Verlag Berlin Heidelberg.
- ARNOTT, M. 1985. The biogas / biofertilizer business handbook.
- ARTI. 2003. *ARTI Biogas Plant: A compact digester for producing biogas from food waste* [Online]. [Accessed 2009-10-23 2009].
- AUSTRALIAN-GREENHOUSE-OFFICE 1997. *Methane Capture and Use-Waste Management Workbook*, Canberra, Environment Australia.
- BANDARA, H. M. C. K., WEERASINGHE, K. D. N. & JAYASINGHE, G. Y. 2007. Application of biogas technology as a renewable energy source and environmental friendly technique to manage solid waste.
- BERGLUND, M. 2006. *Biogas production from a system analytical perspective*. Doctor of Philosophy., Lund University.
- BUDIYANO, WIDIASA, I. N., JOHARI, S. & SUNARSO 2010. The influence of Total Solid Contents on Biogas Yield from Cattle Manure Using Fluid Inoculum. *Energy Research Journal*, 1, 6-11.

- ENERGIE-CITIES. 1999. Biogas-biofuel IILLE (France).
- EPA. 2002. Clean Alternative Fuels: Compressed Natural Gas. Available: [www.epa.gov/otaq/consumer/fuels/altfuels/altfuels.htm](http://www.epa.gov/otaq/consumer/fuels/altfuels/altfuels.htm)
- EVANS, G. 2005. *Biowaste & Biological Waste Treatment*, James & James (Science Publishers) Ltd.
- FERNANDEZ, A., SANCHEZ, A. & FONT, X. 2005. Anaerobic co-digestion of a simulated organic fraction of municipal solid wastes and fats of animal and vegetable origin. *Biochemical Engineering*, 26, 22-28.
- FINSTERWALDER-UMWELTTECHNIK-GMBH-&CO.-KG. 2009. *Reference Study: Increasing Biogas Yield through Addition of Food Waste Moosburg, Germany Waste Water Treatment Plant – Anaerobic Digester* [Online]. Mailinger Weg 5 · D - 83233 Bernau. Available: [www.fitec.com](http://www.fitec.com) [Accessed 2010-06-02 2010].
- GERADI, M. H. 2003. *The Microbiology of Anaerobic Digesters*, Publisher John Wiley & Sons Inc.
- GONZÁLEZ, L. M., COLTURATO, L. F., FONT, X. & VICENT, T. 2010. Anaerobic co-digestion of the organic fraction of municipal solid waste with FOG waste from a sewage treatment plant: Recovering a wasted methane potential and enhancing the biogas yield. *Waste Management*.
- GROOM, R. E. 2007. Anaerobic Digestion –Benefits and Opportunities.
- HANS, C. W. 2006.
- IANGV. 2008. *Emissions* [Online].
- IANGV. 2010. *2009 Natural Gas Vehicles Stats* [Online].
- ILYAS, S. Z. 2006. A case study to bottle biogas in cylinders as source of power for rural industries development in Pakistan. *World Applied Sciences*, 1, 127-130.
- IOWA-FARM-BUREAU 2007. Economics of Biogas.
- J.A. ALVAREZ, L. O., J.M. LEMA 2009. A methodology for optimising feed composition for anaerobic co-digestion of agro-industrial wastes. *ScienceDirect Bioresource Technology*, 101 (2010) 1153-1158.
- JONSSON, O. 2003. Biogas upgrading and use as transport fuel.

- JÖNSSON, O., ERIK POLMAN, JAN K JENSEN, ROLF EKLUND, HÅKAN SCHYL AND STAFFAN IVARSSON 2002. Sustainable gas enters the European gas distribution system.
- KAPDI, S. S., VIJAY, V. K., RAJESH, S. K. & PRASAD, R. 2005. Biogas scrubbing, compression and storage: perspective and prospectus in Indian context *Renewable Energy*, 30, 1195-1202.
- KOLODZIEJ, R. 2007. *Biomethane Fact Sheet.Sequester* [Online]. Washington. [Accessed 2007-03-21 2007].
- KOMPOGAS 2008. From Waste to Energy.
- KOSSMANN, W., PÖNITZ, U., HABERMEHL, S., HOERZ, T., KRÄMER, P., KLINGLER, B., KELLNER, C., WITTUR, T., KLOPOTEK, F. V., KRIEG, A. & EULER, H. 1999. *Biogas Digest*.
- LAMPINEN, A., POYHONEN, P. & HANNINEN, K. 2004. Traffic Fuel Potential of Waste Biogas in Industrial Countries - The Case of Finland. In: SAYIGH, A. (ed.) *World Renewable Energy Congress VIII (WRES 2004)*. Elsevier Ltd.
- LEHTOMAKI, A. 2007. Energy from waste - Sustainable energy production with biogas technology.
- LETTINGA, G., HULSHOFF POL L.W., VAN LIER J.B., ZEEMAN G., VAN HOUTEN R.T., JANSSEN A.J.H. 1995. *Anaerobic Rector Technology, International Course on Anaerobic Waste Water Treatment*, IHE Delft, Wageningen Agricultural University.
- MATA-ALVAREZ, J. (ed.) 2002. *Fundamentals of the Anaerobic Digestion Process*: IWA Publishing.
- MATA-ALVAREZ, J. 2003. *Biomethanization of the Organic Fraction of Municipal Solid Waste*, IWA Publishing.
- MESTREL 2008a. The Use of Biomethan as a Fuel by the Urban Bus Fleet in Lille. *Biomass & Bioenergy* 2008. Tallinn.
- MESTREL 2008b. The use of biomethane as a fuel b the urban bus fleet in Lille (France). *Biomass JA Bioenergia*.
- MINISTRY-OF-ENVIRONMENT-AND-NATURAL-RESOURCES 2005. *Data base of Municipal Solid waste in Sri Lanka*, Pollution control division, Ministry of Environment and Natural Resources.
- MITZLAFF, K. V. 1988. *Engines for Biogas*, Friedr. Vieweg & Sohn Verlagsgesellschaft.

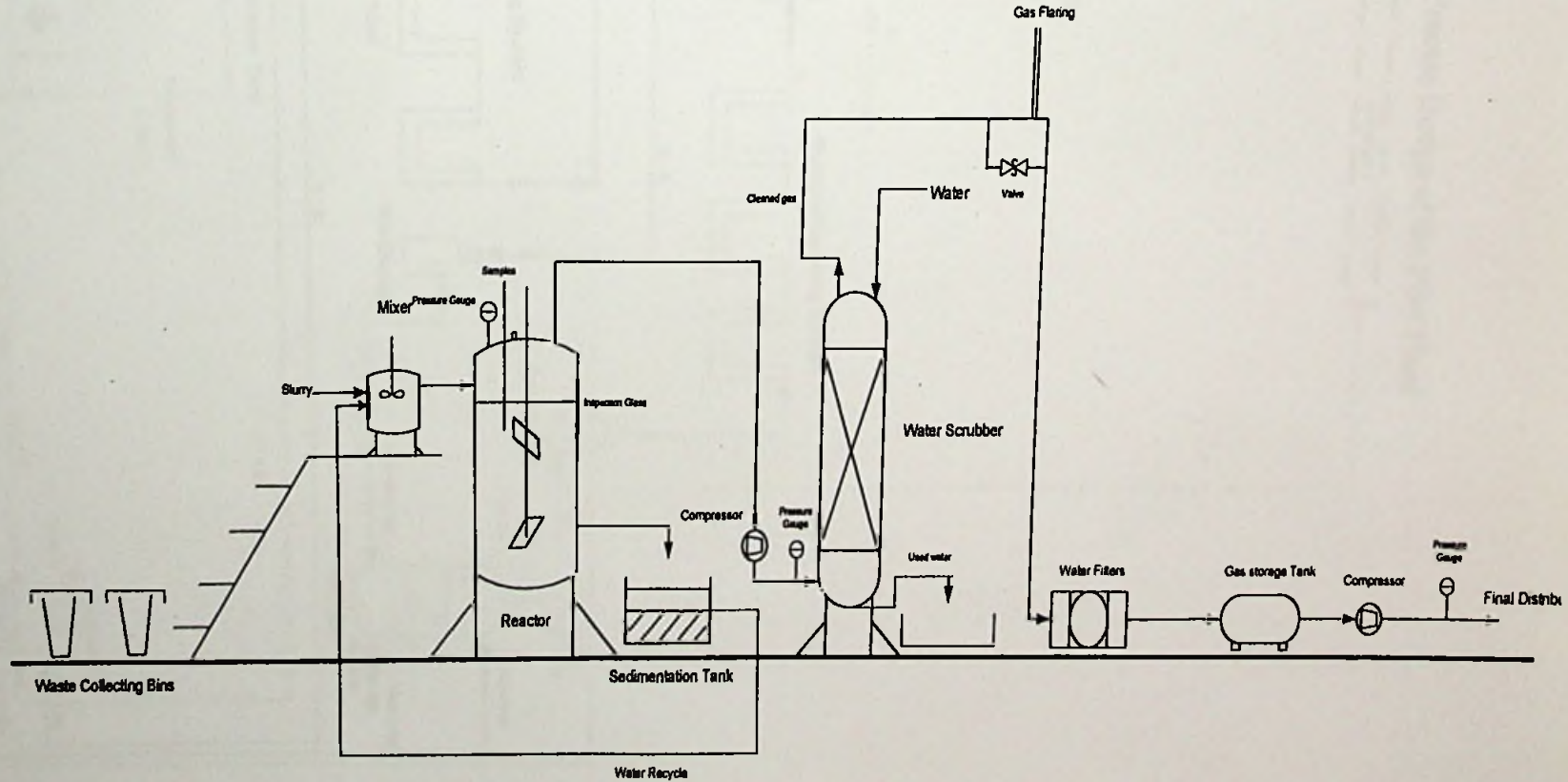
- MOLLOY, S. 2008. UPGRADED BIOGAS FOR VEHICLE FUEL - Experience from Sweden, France, Japan, Iceland and Spain. *Biogas Conference*.
- MURPHY, J. D. 2005a. Anaerobic digestion and biogas. *Composting Conference (Cré)*. Heritage Hotel, Portlaoise.
- MURPHY, J. D. Anaerobic digestion and biogas. *Composting Conference (Cré)*, 2005b Heritage Hotel, Portlaoise.
- NAVICKAS, K. 2007. BIOGAS FOR FARMING, ENERGY CONVERSION AND ENVIRONMENT PROTECTION.
- NSCA, N. S. F. C. A. A. E. P. 2006. *Biogas as a road transport fuel - An assesment of the potential role of biogas as a renewable transport fuel*.
- OFOEFULE, A. U., UZODINMA, E. O., ONUKWULI, O. D. 2009 Comparative study of the effect of different pretreatment methods on biogas yield from water Hyacinth (*Eichhornia crassipes*). *International Journal of Physical Sciences*, 4, 535-539.
- OSORIO, F., TORRES J.C. 2009. Biogas purification from anaerobic digestion in a wastewater treatment plant for biofuel production. *Renewable Energy*, 34, 2164-2171.
- PERSSON, M. 2003. Utvärdering av uppgraderingstekniker för biogas. Svenskt gastekniskt center (sgc).
- PERSSON, M. 2006a. Biogas – a sustainable fuel for the transport sector.
- PERSSON, M. E. A. 2006b. Biogas Upgrading to Vehicle Fuel Standards and Grid Injection. IEA Bioenergy.
- PLOMBIN, C. 2003. Biogas as Vehicle Fuel – a European Overview. Stockholm: Ecole des Mines d'Albi, France.
- RAVINDRANATH, N. H. 2001. Developing High Rate Biomethanation Process as Means To Reduce GHG Emissions in India.
- SARAVANANE, R., MURTHY, D.V.S., KRISHNAIAH, K. 2000. *Environmental issues and managemnet in sago industry for energy production*, Rotterdam, A.A. Balkema.
- SATYANARAYAN, S., RAO, N. N., SHIVAYOGI, RAMAKANT & KAUL, S. N. 2003. Improvement in biogas yield by feed stock amendmets in cattle dung digesters. *Journal of Rural Tech.*, 1, 6.

- SEISLER, J. 2010. Worldwide NGV Update: Growth & Trends, Working Party on Gas-United Nations.
- SENADEERA, W., BARI, S., BURGE, A. & HARRIS, P. 2007. Implementation and optimisation of anaerobic digestion to South Australian Climatic Conditions.
- STAMBASKY, J. 2010. Energy from biogas in the national renewable energy action plan. European Biogas Association.
- THE-AMERICA-BIOGAS-ALLIANCE 1998. Fact Sheet: Sequestering Greenhouse Gases from Landfills, Animal Waste, Sewage, and Other Sources Via Biomethane Production. Washington.
- THEMELIS, N. A. P. U., EDS. 2005. Capture and Utilisation of Landfill Gas. What is the potential for additional utilisation of landfill gas in the USA and around the world? *Renewable Energy*.
- TRAFFIC-AND-PUBLIC-TRANSPORT-AUTHORITY 2000. Biogas technology and biogas use in Sweden. Gothenburg.
- TUSAR, R. 2009. Profiting from the use of Biogas - The Panvita Case.
- UNDEN, P. 2007. Bio-Methane as Transport Fuel. Swedish Biogas International AB.
- WAKDIKAR, S. 2002. Compressed natural gas: A problem or a solution. *CURRENT SCIENCE*, 82.
- ZHANGA, P., ZENGA, G., ZHANGB, G., Y. LIA, ZHANGA, B. & FANC, M. 2007. Anaerobic co-digestion of biosolids and organic fraction of municipal solid waste by sequencing batch process.

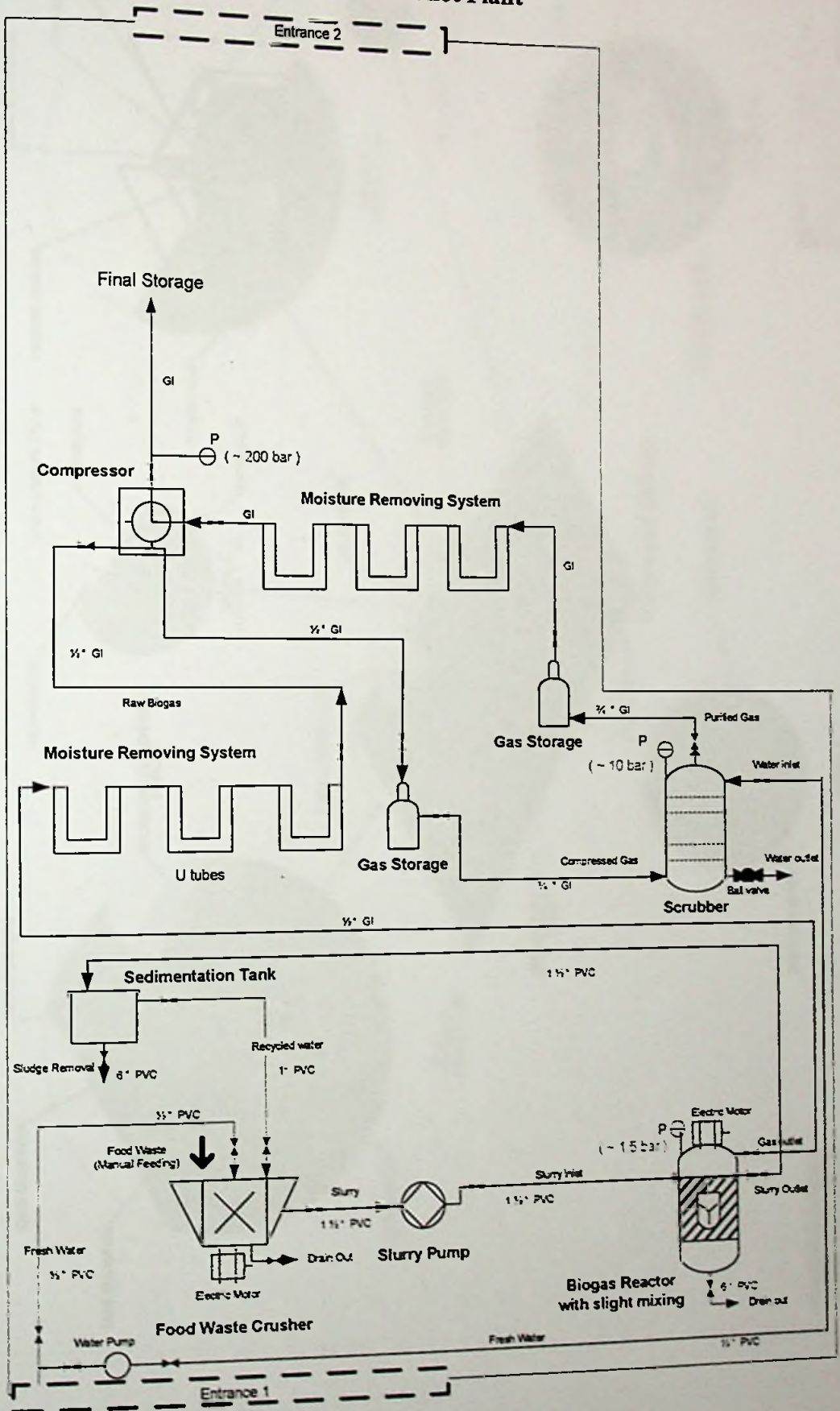
# APPENDICES

## Annex A: Initial Process Design of the Pilot Plant

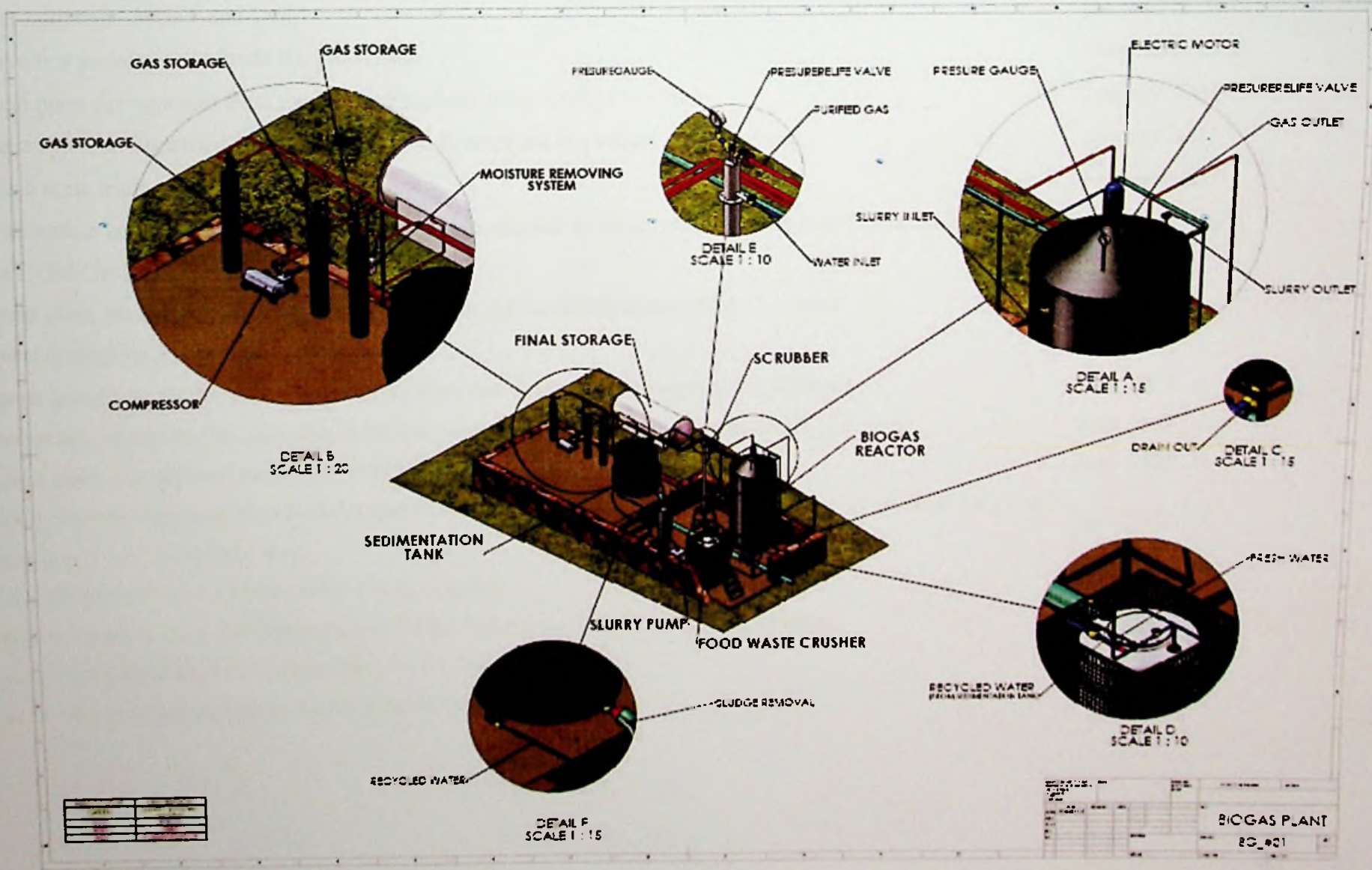
### PROCESS FLOW DIAGRAM



# Annex B: Final Process Design of the Pilot Plant



# Annex C: Final Constructed Pilot-scale Biogas Plant





## Annex D: Product Timeline

Project initiative - MOST and UOM	November 2006
Receive first instalment of funds Rs. 2,000,000/-	December 2006
Request plant site approval from the Works Engineer at the UOM (1st time)	January 2007
Request approval from the Department of Public Enterprises to procure a three wheeler	January 2007
Start lab scale trials	February 2007
Site allocation committee approval with the recommendation to concurrence of Director (Physical Education) at the UOM (1st time)	March 2007
Request plant site approval from the Director (Physical Education) at the UOM (1st time)	March 2007
Request quotations for the biogas reactor vessel	June 2007
Request quotations for the food waste crusher from one source Odiris Engineering Company	June 2007
Rejected the request for the plant site by the Director (Physical Education) at the UOM (1st time)	June 2007
Request plant site approval from the Works Engineer at the UOM (2nd time)	June 2007
Planning and Development Committee approval with the recommendation to concurrence of Director (Physical Education) at the UOM (2nd time)	June 2007
Received approval from Director (Physical Education)	June 2007
Grant the approval from the Department of Public Enterprises to procure a three wheeler	June 2007
Request Quotations for a CNG thee wheeler (1st time)	June 2007
Receive and evaluate quotations for the food waste crusher	July 2007

Request quotations for the slurry pump (1st time)	July 2007
Receive and evaluate quotations for the biogas reactor vessel	August 2007
Conclude to buy the biogas reactor vessel from Sesatha Enterprises and send the purchase order	August 2007
Receive and evaluate quotations for the slurry pump (1st time)	August 2007
Forward the site plan and BOQ to the Works Engineer at UOM to proceed the construction of the plant building	August 2007
Request quotations for the slurry pump (2st time)	September 2007
Receive and evaluate quotations for the slurry pump (2st time)	October 2007
Awarding letter for the construction of the plant building to Wickramasekara Builders (Rs. 365,839.20 + VAT)	October 2007
Cancellation of the award offered to Wickramasekara Builders due to not starting the job on time	October 2007
Awarding letter for the construction of the plant building to Ruwan Trade Centre (Rs. 415,454/- + VAT)	October 2007
Conclude to buy the slurry pump from Solex Eng. (Pvt) Ltd and send the purchase order	November 2007
Request quotations for the scrubber	November 2007
Receive and evaluate quotations for the scrubber	December 2007
Request more funds from MOST	February 2008
Receive the slurry pump	March 2008
Grant additional funds from MOST (Rs.800,000/-)	April 2008
Receive 2nd part of funds (Rs.650,000/-)	April 2008
Request quotations for the supply and install pipelines for the plant building	April 2008

Completion of constructing the plant building	April 2008
Lifting the roof	April 2008
Test empty gas cylinders for reuse	May 2008
Receive and evaluate quotations for the supply and install pipelines for the plant building	June 2008
Conclude to work with Tritech Engineering Company for the supply and install pipelines for the plant building	June 2008
Request Quotations for a CNG thee wheeler (2nd time)	June 2008
Receive the biogas reactor vessel	July 2008
Receive the scrubber	August 2008
Receive the biogas reactor vessel	August 2008
Receive and evaluate quotations for a CNG three wheeler	August 2008
Provide power supply for the plant building from Electrical Superintendent at UOM	September 2008
Request quotations for fixing bamboo tats for windows	September 2008
Receive and evaluate quotations for fixing bamboo tats for windows	October 2008
Complete the supply and install pipelines for the plant building	November 2008
Start feeding	November 2008
Awarding letter for fixing bamboo tats to Mr. Asanka Sanjeewa (Rs. 48,545/-)	November 2008
Complete fixing bamboo tats	December 2008
Receive 3rd part of funds (Rs.1002,500.75)	December 2008
Request Quotations for a LPG thee wheeler	January 2009

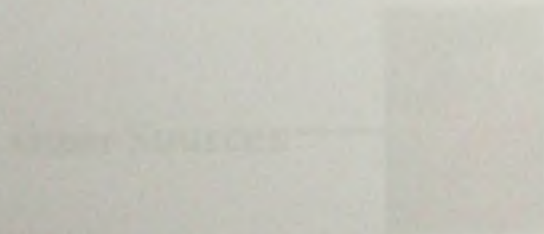
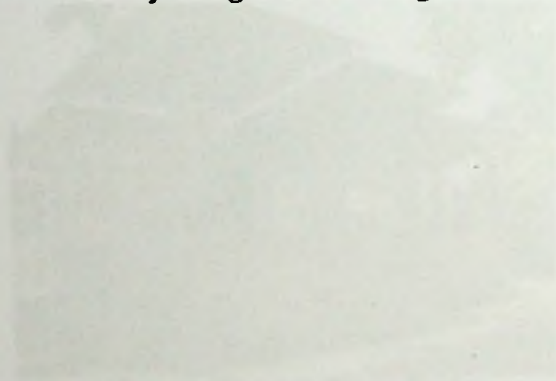
Receive and evaluate quotations for a LPG three wheeler	March 2009
Conclude to buy the LPG three wheeler from David Peris Motor Company	March 2009
Receive and checking the LPG three wheeler	May 2009
Request from VC to register the LPG three wheeler as a university vehicle	May 2009
Registration of the LPG three wheeler	May 2009
Removal of the slurry inside	June 2009
Completed Biogas Test Bench design	October 2009
Received the “gas gun” from Mr. Heshan ( Laughs Gas )	October 2009
Biogas dry batch system processed	October 2009
Started feeding to reactor by using Cow dung and Canteen Waste	November 2009
First test run was conducted with the support from “Master Divers” and successfully run for a long distance	November 2009
Second test run for three wheeler	December 2009
Changed the feeding pattern and conducted tests for several parameters to find out the effect	December 2009
Removed all liquid inside the reactor and washed out from fresh water to start pilot plant in fresh conditions	February 2010
Replaced the packing in the scrubber by using rubber packing	February 2010
Completed emission test from biogas	February 2010
Completed removing slurry inside the reactor	March 2010
Started Pilot plant from fresh conditions with activated sludge as inoculums	April 2010
First flame from the gas produced in the pilot plant.	May 2010

Conducted a test run by using pilot plant biogas

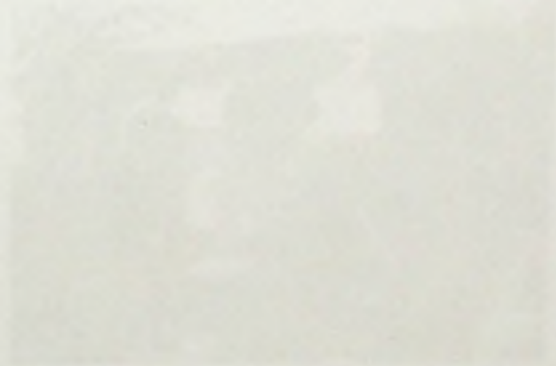
May 2010

Conducted test runs by using BURNS biogas

May 2010



B  
I  
O  
G  
A  
S



Plant 1  
Burns Facility  
In the Town  
of Burnsville

Plant 2  
Burns Facility  
In the Town  
of Burnsville

Plant 3  
Burns Facility  
In the Town  
of Burnsville

# Annex E: Operating vehicles with biogas fuel



Figure 1: Pilot-scale Biogas Plant



Figure 2: Dry Batch Pit



Other Sources

B  
I  
O  
G  
A  
S



Figure 3: Biogas Feeding to the Three Wheeler



Figure 4: First Ignition



Figure 5: First Run

