Republic of Rwanda
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In Charge of Science and Technology

3rd International Conference on Appropriate Technology

Kigali, Rwanda, November 12 – 15, 2008

"Promoting Research and Practice in Appropriate Technology: Energy Solutions in the Era of Climate Change"

PROCEEDINGS OF ORAL PLATFORM PRESENTATIONS

J. Tharakan and J. Trimble, Editors
Northern California Council of Black Professional Engineers (NCCBPE)

__K. Ngige, Clean Air Solutions, Nairobi, Kenya__
__B. Stephenson, Howard University, USA__
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The Historical Development of the International Conferences on Appropriate Technology

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The Relevance of Appropriate Technology

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T. Nkurunziza[1] and J. Ntaganda[2]
[1]Institute of Scientific and Technological Research (I.R.S.T.),
P.O.Box 227, Southern Province, RWANDA; E-mail: nkurtheo@yahoo.fr
[2]National University of Rwanda, Faculty of Sciences, Southern Province, Rwanda

2. **Studies on Alcohol Production from Sweet Potato**

M. Sankaranarayanan and P Mukarukaka
Institut Supérieur d'Agriculture et d' Elevage, ISAE, Busogo
Post Box No. 210, Musanze, RWANDA ; E-mail: sankar081954@yahoo.co.in

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Kinyua Ngige
Clean Air Energy Solutions. P.O. BOX 70550-00400
Nairobi, KENYA; E-mail: cleanairkenya@gmail.com

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William M. Goriwondo, Davison Zimwara, Nicholas Tayisepi
National University of Science and Technology
Department of Industrial and Manufacturing Engineering, P.O. Box AC 939
Ascot, Bulawayo, ZIMBABWE; E-mail: wgoriwondo@nust.ac.zw

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Safari Bonfils and Jimmy Gasore
Department of Physics, National University of Rwanda
P.O. Box 117, Huye, RWANDA; E-mail: **bsafari@nur.ac.rw**

2. **Analysis, Design and Implementation of Solar Supply for Remote Flux Tower and Village Community**

J. Tharakan, M. Mitchell, and G. Jenkins
Departments of Chemical Engineering and Physics, Howard University
Washington, DC, USA; E-mail: jtharakan@howard.edu

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J. Chaney, M. J. Clifford, and R. Wilson
School of Mechanical Engineering, School of the Built Environment
University of Nottingham, UNITED KINGDOM
E-mail: laxjc4@nottingham.ac.uk

4. **Factors Associated with the Adoption of Improved Cook Stoves in Southern Parts of India**

K. S. Pushpa
Home Science Department, Gandhigram Rural University
Gandhigram, Tamil Nadu, INDIA; E-mail: kspushpasarma@yaoo.com

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Sultana, Tanzeen
Department: Mechanical & Manufacturing Engineering, University of New South Wales, Australia, 4 / 25 Hillard Street, Wiley Park, NSW 2195, AUSTRALIA
Email: taneen38@yahoo.com

2. **Comparative Study on Utilization of Internal Combustion Generator Engines and Hydropower Plants in Solving Rwandan Electrical Energy Problem**

M. N. Irechukwu, C. Cyusa and O. Muhayimana
National University of Rwanda
Faculty of Applied Sciences, Dept. of Electrical & Electronic Engineering
Kigali, RWANDA; E-mail: mirechukwu@nur.ac.rw, mikeirechukwu@gmail.com

3. **Breeding a Better Stove**

Hugh Burnham-Slipper, Michael John Clifford, Stephen J Pickering
School M3, The University of Nottingham
University Park, Nottingham NG7 2RD
UNITED KINGDON; E-mail: laxjc4@nottingham.ac.uk

4. **Who and What Will Their Will be the Players in Green Technology Role Be?**

Hattie Carwell
Museum of African American Technology (MAAT) Science Village, P.O. Box 1686, Oakland, CAE-mail: hattie.carwell@att.net

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Robby Yussac Tallar[1], Inge Komardjaja[2]

Maranatha Public Service and Research Centre (LPPM),
Jl. Prof. drg. Suria Sumantri, MPH No. 65 Bandung 40164 West Java, INDONESIA
Email: robby.yt@eng.maranatha.edu or robbyyussac@yahoo.com

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C. Ndayisaba, B.R. Ngirabakunzi, L. Nzabonantuma and A. Kabanda
Institute of Scientific and Technological Research (IRST)
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RWANDA; Email: ndayicy@yahoo.fr

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M.S. Biju and **G. K. Verghese**
Department of Civil Engineering, National Institute of Technology Calicut
Kozhikode, Kerala 673 601
INDIA; E-mail: bijums1980@gmail.com

4. **Zinc and Chromium Removal Mechanisms from Industrial Wastewater by Water Hyacinth, *Eichhornia crassipes (Mart.) Solms***

R. J. Gakwavu, B.C. Sekomo and I. Nhapi
Department of Civil Engineering, Faculty of Applied Sciences
National University of Rwanda
P.O.Box. 117 Huye, Southern Province
RWANDA; E-mail: gakwavurjohn@yahoo.fr

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D. Muhirwa, **I. Nhapi** and N. Banadda
Faculty of Applied Sciences, National University of Rwanda,
Butare, RWANDA; E-mail: muhird@yahoo.fr

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B. A. Gyampoh, A.S. Amisah and M. Idinoba
Faculty of Renewable Natural Resources
Kwame Nkrumah University of Science and Technology (KNUST)
Kumasi, GHANA; E-mail: b.gyampoh@gmail.com

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S. V. Srinivasan, E. Ravindranath, R. Sunthanthararajan, K. Sri Balakameshwari, K. Thirumaran, K. Chitra, B. Umamaheswari
Department of Environmental Technology,
Central Leather Research Institute, Chennai, INDIA; Email: srinivasansv@yahoo.com

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K.R.Santhi and G. Senthil Kumaran
Kigali Institute of Science and Technology (KIST)
Kigali, B.P.3900, RWANDA; Email: santhikr@yahoo.com

2. **Enhancing Public and Private sector delivery through Rwandan National Smart Card Initiative**

Sashi Kumar Sivam
Senior Consultant
MSCTC, MALAYSIA
E-mail: sashi@msctc.com.my

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A. Nyamvumba [1], C. M. Kumile[2], J. Trimble [3], and T. Nenzhelele [4]
[1]Industrial Engineering Department, [2]Manufacturing Department, and [4]Industrial Engineering Department
Tshwane University of Technology, SOUTH AFRICA;
E-mail: 2andrewn@gmail.com
[3]Systems and Computer Science Department, Howard University, Washington DC, USA; jtrimble@howard.edu

4. **A National Framework for Infusing Information Technology in the Decision Support Process**

John Trimble and Andrew Nyamvumba[2]
[1]Systems and Computer Science Department
Howard University, Washington DC, USA; E-mail: jtrimble@howard.edu
[2]Rwanda Information Technology Authority, Research & Development Dept, Ministry of Science and Technology, Kigali RWANDA

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Mohamad Abbas, Hisham Abu Shama and **Gada Kadoda**
Department of Computer Science, University of Khartoum
Khartoum, SUDAN; Email : gadoda@gmail.com

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Ngarambe Donart
Kigali Independent University, Kigali, RWANDA
E-mail: don_ngrambe@yahoo.com

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Mpofu Irvin

Umutara Polytechnic, P.O. Box 57
Nyagatare, RWANDA; E-mail: impofu66@yahoo.com

4. **Turning Stories into Creative Content**

Samuel Suraphel

PUERTO RICO; E-mail : suraphels@betabahil.com

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[1]Tagwireyi, T., [2*]**Mupangwa, J**. F., [3]Jepsen, J. and [4]Mwera, P.
[1]Department of Environmental Science, Bindura University of Science Education, P. Bag 1020, Bindura, ZIMBABWE
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[3]Tree Africa, P. O. Box AV 231, Avondale, Harare, ZIMBABWE
[4]Lake Harvest International, P. O. Box 40, Kariba, ZIMBABWE
*Corresponding author: tjmupangwa@yahoo.com

2. Milk Production from Lactating Holstein Cows Fed Cereal-Tree Forage Legume Silages

[1*]**Mupangwa J.F**., B. Z. [2]Mugweni, B.Z., M. [3]Titterton, M., B. V. and [4]Maasdorp, B.V. and [3]F. Gandiya
[1]Umutara Polytechnic, Faculty of Agriculture, P. O. Box 57, Nyagatare, RWANDA
[2] Department of Livestock Production and Development, Ministry of Agriculture, P O Box 143, Mutare, ZIMBABWE
[3]University of Zimbabwe, Department of Animal Science, Harare, ZIMBABWE
[4]University of Zimbabwe, Department of Crop Science, , Harare, ZIMBABWE
*Corresponding author: tjmupangwa@yahoo.com

3. Alfalfa Yield Under Subsurface Drip Irrigation Applying Secondary domestic Effluent

Shija Kazumba[1,2,*], Leonid Gillerman[1], and Gideon Oron[1]
[1]Department of Environmental Hydrology and Microbiology, Ben-Gurion University of the Negev, Jacob Blaustein Institutes for Desert Research, Kiryat Sde-Boker 84990, ISRAEL
[2]Department of Civil Engineering, Dar es Salaam Institute of Technology P.O.Box 2958, Dar es Salaam, TANZANIA; Email: kazumba@bgu.ac.il

4. Smallscale Palm Oil Process Improvement for Poverty Alleviation and National Development

N. Kyei-Baffour and C. Manu
Department of Agricultural Engineering, Faculty of Mechanical and Agric. Engineering, College of Engineering,
Kwame Nkrumah University of Science and Technology (KNUST),
Kumasi, GHANA, E-mail: nicholaskyeibaffour@yahoo.co.uk

5. Upright cowpea varieties outyield trailing and climbing cowpea varieties when intercropped with maize and leaf stripping and detasselling of maize enhances productivity of the intercrops

A. B. Mashingaidze[1] and R.D. Katsaruware[2]
[1]Umutara Polytechnic, P O Box 57, Nyagatare, RWANDA; E-mail:
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Pleasant, Harare, ZIMBABWE; E-mail: abmash@yahoo.com

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L. B. Ndlovu and **S. I. Umenne**
[1]Civil and Water Engineering, National University of Science and Technology, P O Box AC 939, Ascot, Bulawayo, ZIMBABWE; E-mail:lbndlovu@nust.ac.zw or lookoutn@yahoo.co.uk
[2]Faculty of the Built Environment (FOBE), National University of Science and Technology, P O Box AC 939, Ascot, Bulawayo, ZIMBABWE; E-mail: umenne@nust.ac.zw or sikumenne@yahoo.com

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Mukantwali C, Tiisekwa B, Ndirigwe J
Institut des Sciences Agronomiques du Rwanda
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RWANDA; E-mail: mukantwalichristine@yahoo.fr

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Paul Chatikobo[1], M. Manzi[2], J. Kagarama[1], J.D. Rwemarika[2], and O Umunezero[2]
[1]Faculty of Veterinary Medicine, Umutara Polytechnic, P.B 57, Nyagatare Eastern Province, RWANDA
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E-mail: paulchatie@yahoo.com; paulkobo@gmail.com

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Brian Stephenson
Department of Civil Engineering, Howard University
Washington, DC 20059, USA; E-mail: stephensonb@comcast.net

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Umutara Polytechnic, Faculty of Veterinary Medicine
P.B 57, Nyagatare, Eastern Province, RWANDA; E-mail: **paulchatie@yahoo.com**

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M. Manzi, T. Rutagwenda, N. Kanuya and P. Chatikoba
Institute des Sciences Agronomiques du Rwanda (ISAR)
Nyagatare Research Station, B.P 84
Eastern Province, Rwanda; E-mail: manzimax2002@yahoo.co.uk

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Charles C. Verharen
Department of Philosophy, Howard University, Washington, DC, USA
E-mail: cverharen@howard.edu

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3. **Laboratory scale biogas production from geranium distilled leaves**

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P.O Box 62000, Nairobi, KENYA; E-mail: **mgmkituu@yahoo.com**

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Kumasi, GHANA; E-mail: akowuahjoe@yahoo.co.uk

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Alexio Mubaiwa
Practical Action Southern Africa
No. 4 Ludlow Road, Newlands, P.O. Box 1744, Harare, Zimbabwe.
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C. Chiyaka, J.M. Tcheunche, W. Garia and S. Dube
National University of Science and Technology
Bulawayo, ZIMBABWE; E-mail: cchiyaka@nust.ac.zw; shdube@nust.ac.zw

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Peter M. Corridon
The Center for Biomedical Imaging, The University of Trinidad & Tobago
Trinidad & Tobago, WEST INDIES**E-mail: peter.corridon@utt.edu.tt**

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Robinson Onyango Manguro
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The Historical Development of ICAT – International Conferences on Appropriate Technology

John Trimble, Howard University, Washington, DC

The first ICAT was held in July 2004 in Bulawayo Zimbabwe. This effort drew on previous work by a network of academics at Howard University that started with the
formation of the Howard University Project on Appropriate Technology (HUPAT) in 1998.

HUPAT had been involved with local and national conferences in the United States, hosted at
Howard University.
The 1st ICAT addressed the theme of "A Knowledge management Approach to the Development of Appropriate Technology, with a focus on Sustainable land-based projects".
This was a timely theme since Zimbabwe was concerned with projects that would assist new
farmers following their 'fast track land reclamation' process. This first effort was largely
possible through the support of academic staff at the National University of Science and
Technology (NUST) in Bulawayo Zimbabwe. Paper sessions addressed: industry and production; construction and architecture; transportation and solar technology; water,
agriculture and environment; and knowledge management and appropriate computing. [1]
In preparation for the 2nd ICAT we actively sought to expand the international planning committee. We also increased the role of Howard University and added the Northern California Council of Black Professional Engineers (NCCBPE) as an active cosponsor.
The current interest in health in underdeveloped countries was addressed. Once again the conference was hosted by NUST in Bulawayo Zimbabwe. It took place two years
after the first ICAT in July 2006. The theme that year was "Sharing the Knowledge from
Research and Practice in Appropriate Technology, with a focus on Health-Related projects".
The highlight of the conference was the 'health related' paper session and special talks by
health experts. Other paper sessions included: knowledge management; energy and physics;
water and agriculture; environmental; and architecture and small-scale industry. [2]
Active organization for the 3rd ICAT began in April 2007. We expanded our international planning committee to include 12 countries. For the first time we involved
multiple universities in the host country: Kigali Institute of Science and Technology (KIST);
the National University of Rwanda (NUR); Umutara Polytechnic University; Universite Libre
de Kigali (ULK) and Kigali Health Institute (KHI).
At an early point in the conference organizing, the Ministry of Science and

Technology in the President's Office provided strong support. This has been instrumental in expanding our work in appropriate technology. We owe as special thank you to Minister Murenzi. The theme of this year's conference is: "Promoting Research and Practice in Appropriate Technology: Energy Solutions in the Era of climate change"

A common thread through all our conferences has been to connect research with practice and to use knowledge technology to make best practices accessible beyond the conference venue. Our commitment to the active promotion of 'technology to empower the people' will make an impact on research, practice and policy regarding science, technology and development planning.

Any vision of a better world must include a serious shift in how resources are used regarding science and technology. We believe that the work of our ICATs will make a contribution to this process.

[1] Mhlanga, S. and J. Trimble, editors, Proceedings from 1st ICAT, Buluwayo Zimbabwe, July 15-17 2004

[2] Muchabayiwa, B. and J. Trimble, editors, Proceedings from 2nd ICAT, Bulawayo Zimbabwe, July 12-15 2006

The Relevance of Appropriate Technology

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The first technologies ever developed, whether the club as a tool, the spear or fire, were tools appropriate to satisfy the needs of the community and enhance the community's ability and capability to survive and endure. Since the beginning of the human-technology relationship, the development of technology and the purposes and the needs these technological developments served have become increasingly complex from that early dawn. In the late twentieth century and as we enter the closing years of the first decade of the twenty-first century, today's world of globalized and increasingly privatized resource and capital flows, the notion that an appropriate technology can be defined and characterized may seem increasingly improbable and unlikely.

However, as recent market and economic dysfunction have amply demonstrated, globalized privatization and unregulated transnational capital and resource flows with little government and state oversight, also means globalized and almost ubiquitous economic difficulties across diverse national economies and socio-techno-economic systems. Whether there is a need for appropriate technology in such a context is a valid question and the answer must take into account economic and livelihood realities of local communities, especially those in the countries of the global south.

The complexity of this socio-technological relationship must be seen in the context of over two thousand years of social and technological development which have resulted in some of the wealthiest and most prosperous of times for certain members of the global population.

However, at this late stage in human civilization's development, of the six and a half billion people who inhabit this planet, almost a half, have no regular and consistent access to clean, potable water. These same communities also lack access to hygienic and sanitary waste and sewage disposal systems. Almost two-thirds lack access to the world-wide web and are left on the wrong side of the digital divide - effectively being left out of the conversation and cut off from the immense wealth of resources available on-line.

This disconnect, between the harsh realities of inequitable resource distribution and access to technology, and the amazing and extraordinary technological developments and advances of the previous two centuries, speaks clearly to a desperate need for a renewed focus and emphasis on technology that is appropriate to the establishment of a just, equitable and fair global social order. This must be a global social order defined by a human-technology relationship that seeks to harness the immense creativity of the human species in their ability to respond to their environment and engineer it to their benefit for a sustainable existence within their own socio-geographical spaces.

Although E. F. Shumaker introduced into the western scientific and rational consciousness the notion of small as beautiful and technologies that responded to human communities at scales that were manageable, controllable and appropriate to the context of its development and application, indigenous peoples from across the globe have developed and implemented technological solutions relevant to their time and space; indeed relevant and appropriate to their socio-economic and socio-ecological niches and habitats. These repositories of indigenous knowledge have ranged from the oral (such as the oral traditions of the Native American Indians and various African tribes and nations) to the documented and written (such as technological and scientific handbooks from India, China and the Arab nations), and these can provide a rich resource for current practitioner' s as we seek to develop solutions to problems that have grown as complex as some of the proposed solutions.

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Clearly, then, the relevance of appropriate technology cannot be disputed. In the context of the 21st century, the principles and criteria that define and determine appropriateness of technologies must be re-articulated and under scored. Appropriate technology means many different things to different people. Generic searches on the internet reveal thousands of sites that respond to the search engines calling, revealing that meanings can often be elusive and illusory.

Nevertheless, although appropriate technology, or AT, is difficult to define and its development and implementation have been a source of debate for some time [1], there is general agreement on some of the governing characteristic of appropriate technology. It is clear that AT should normally require only small amounts of capital. AT must emphasize, wherever possible, the use of local materials. Implementation of AT' s should focus on relatively labor intensive technological solutions that individual' s in community' s can participate in. This suggests that AT should tends towards the smaller scale and be affordable.

The community based nature of AT requires that the technological solutions being developed should be understandable, controllable and maintainable without unduly high levels of education and training; at the same time, AT should be adaptable and include local communities in innovation and implementation. Finally, adverse impacts on the environment should be avoided and the sustainable nature of the technological solution should be emphasized [2]. Naturally, given the huge divide in resource access and availability, AT will encompass diverse sets of tools, processes and technologies, but will be focused on sustainable development.

The rationale of AT resides in its empowerment of people at the grass roots community level. Development professionals agree that local needs can be met more effectively with the community working to address their own problems. The rationale is also grounded in minimization of financial, transportation, education, advertising, management and energy services and costs with the goal of engendering self-sustaining and expanding reservoirs of skills within a community. The result is a lowering of economic, social and political dependency, and a move towards sustainable development that is focused on people' s needs and is grounded in empowerment through education, technology transfer, capacity building and local control.

AT could never have been more relevant. The diverse set of technologies that are part of the different focus areas of the conference demonstrates the variegated needs that appropriate technologies can be developed and implemented in a sustainable manner, and speaks to the ever-present need to develop and extend these efforts. In concluding, it must be emphasized that appropriate technologies will then necessarily range from the basic and "primitive" technologies required for water supply and sanitation to the more sophisticated and complex including alternative energy technologies focused on renewable resroucres to the wireless rural internet that enable villagers to be valued participants in the global economy.

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[2]Darrow and Saxenian, *Appropriate Technology Sourcebook*, Volunteers in Asia, Stanford, CA (1986).

Laboratory scale biogas production from banana tree residues

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Abstract

The present study aimed mainly at recovering all the residues of banana by producing a firewood alternative source of energy: the biogas, and an organic fertilizer: the effluent. Before conducting an anaerobic fermentation, all the parts of banana tree have been weighed in order to determine their weight to weight ratio. Thereafter, they have been cut into small pieces of almost 2cm, and then aerobically fermented for one week prior to an anaerobic fermentation (biomethanisation). The anaerobic fermentation was carried out during 79 days under a mean temperature of 37.4° C. Experiments have been done in two laboratory digesters of 50L each, the first have received the residues alone and the second the residues *mixed with cow dung. The best results were obtained under those last conditions since with a mixture of 12.6Kg (banana stems): 2.1Kg (banana leaves): 1.5Kg (ripened banana peels): 5.4Kg (cow dung): 17.5Kg (water), a total volume of biogas of 733897.6ml, a daily volume production of 9289.84ml, a productivity of 0.2698m^3/Kg.DM, a biogas composition of 58.07% CH_4 and 41.93% CO_2 and a calorific heat value of 21,647 kJ/m^3 were obtained. Moreover, the effluents constitute a fertilizer of good quality.*

Introduction

Banana tree is an important crop to Rwandan population. Due to its dietary, economic as well as social values, banana tree has been qualified as the 《 cow of the poor 》 [1]. In fact, on top of serving as food, it is used to prepare a traditional drink, locally known as 《URWAGWA 》 which contributes to income generation for many families and, especially in rural areas, plays a vital role during social festivities like dowry hand over, marriage, *etc*. As a matter of fact, banana contributes to 60-80% of household income in major banana growing zones [2] like the Eastern part, the Western region coastal to Lake Kivu and the volcanic region in the Northern part of the country. Climatic conditions for banana are a mean temperature of 15-30° C, an altitude of 1000 to 1200 m and enough rainfall exceeding 100mm/month [3;4]. Though many banana varieties including the one for cooking, the one for dessert and the one meant to produce local wine exist in Rwanda, the last variety is predominant and counts for 60% [2]. The present work focuses on a predominant wine producing variety locally called 《 GISUBI 》. In 2004, Rwanda produced 2469741 tones of all banana varieties on a total cultivated area of 363383 ha, *i.e.* a mean yield of 6.8 tones/ha [5]. Banana plantation occupies on itself 23% of the total arable land [2] and its production is almost the half of the total subsistence crops. Therefore, at harvest, banana tree generates a lot of wastes since the edible part of it is only 8.54% of the total biomass. Therefore, banana tree residues represent undoubtedly a good choice and an appropriate biomass for biogas production in Rwanda since they are sufficiently abundant and easily accessible to the majority of the population. Hence, biogas production from those residues could be one of possible solutions in order to reduce the problem of lack of energy at the household level in Rwanda but also in order to preserve our forests which are being intensively cut.

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Particularly, in case of biogas production it is advisable to use all the parts of banana tree: stems, leaves and peels since they all are biodegradable.

The main objective of this study is to test, at the laboratory scale, the ability of all banana tree residues, to produce biogas. The specific objectives are:

- To produce, from banana tree residues, an alternative fuel in replacement of wood;
- To produce an organic fertilizer from banana tree residues;
- To minimise the use of animal biomass in biogas generation.

Material and methods

Raw material was composed of different parts of banana tree which are stem, leaves and peels. All this raw material has been collected at Mpare, Huye district, Southern province during dry season of July. The weight of each component was determined prior to any physical treatment in order to determine the weight/weight ratio of each. Before being loaded into the laboratory digesters, the banana tree components were cut into small pieces of 2cm and then put into an open cask where they aerobically fermented during one week. The purpose of this composting process is to make the wax material which would complicate the anaerobic fermentation, loose [6]. During this aerobic fermentation, one litre of water was poured over the composting mass which was turned up and down every day in order to facilitate the process as well as to allow equal air distribution. After one week of anaerobic fermentation the material was introduced into 50 litre digesters together with a certain quantity of active sludge from a well functioning digester. This sludge, called innoculum, represents 30% of the total load [6]. Table 1 represents the quantities of different raw materials loaded while Figures 1 and 2 describes the laboratory digesters used which will be symbolised by Dig I and Dig II.

Table 1 Quantities and ratios of different raw material loaded

	Digesters			
	Dig I		**Dig II**	
Different biomass (Kg)	**Quantity (Kg)**	**Ratio**	**Quantity (Kg)**	**Ratio**
Stems	12.6	8.4	12.6	8.4
Leaves	2.1	1.4	2.1	1.4
Peels	1.5	1	1.5	1
Water	17.5	11.7	17.5	11.7
Cow dung	0	-	5.4	3.6
Inoculum	4	-	4	-
Total	37.7	-	43.1	-
Dry Matter (DM)	1.79	5.3%	2.72	6.3%
C/N Ratio	-	40.6	-	37.9

Figure 1 Laboratory digester Figure 2 Heat stabilisation box

Dry matters content (DM) of raw material was determined by drying a fresh sample into an oven set to 105° C [7]. The result in percentage is a ratio between a constant weight of the sample over the weight of the fresh sample before drying. Volatile matters content (VM) was determined by calcination of DM at 600° C [7]. From the ash obtained the percentage of VM was determined.

The wet oxidation method following Schlichting and Blume in 1966 [8] was used to determine the total carbon. After digestion of a sample in presence of a concentrated acid (H_2SO_4, 97%) with the aid of an oxidising agent ($K_2Cr_2O_7$, 2N), the concentration was given by a u.v/visible spectrophotometer at a wavelength of 578nm. The milligrams (the result of a spectrophotometer) are converted into percentage as follows:

$$\%\,C = \frac{mg\ of\ carbone\ (spectrophotometer)}{10 \times weight\ of\ the\ sample\,(g)}$$

The total nitrogen was determined using the classical Kjeldahl method as described by Blume (1966) and USDA (1972) while the total phosphorus was determined by the ascorbic acid method by IITA (1978) [8].

Ammonium, NH_4^+, was analysed using the Nessler reagent method [7]. The nitrite NO_2^- and nitrate NO_3^- ions were analysed following the α-naphtylamine in presence of sulfanilic acid and the phenoldisulfonic acid methods respectively [9]. Various ions including sodium, potassium, calcium, magnesium, iron, manganese, zinc and copper were also analysed on an atomic absorption spectrophotometer at their respective wavelengths [8].

The volume as well as the composition of biogas were determined by an Orsat apparatus. The leading principle of this apparatus is the ability of some gases to be absorbed into specific solutions. In presence of an alkaline solution, KOH 40% in our case, the CO_2 was absorbed forming a soluble salt (K_2CO_3). Hence with a known volume of biogas (100mL) it was possible to quantify the absorbed gas (CO_2) and the remaining one was taken as methane. The biogas heating value was calculated from the fact that the heat value of pure methane is 37,278 kJ/m^3 [10]. This value was then multiplied by the biogas percentage in methane.

Gasholder Fermentation chamber
Stirring device
Hydraulic joint
Gasholder
Bearer
Metallic tub Biogas exit pipe
Wood crate
Insulator
(wood shavings)
Water
Thermostat cable

Results and discussion

Weights of different parts of banana

Weights of different parts of banana, their relative ratios values and percentages are presented in Table 2.

Table 2 Weight, ratios and percentages of different parts of banana (Kg)

Sample	Fresh banana	Stems	Leaves	Ripe banana	Peels
1	8.00	28.00	3.50	7.00	3.00
2	10.00	35.00	5.00	9.00	4.00
3	12.00	38.00	7.50	10.80	4.80
4	13.00	45.80	8.00	11.40	5.80
5	15.00	52.60	9.50	13.50	6.20
Average	11.60	39.88	6.70	10.34	4.76
Ratio	**2.44**	**8.38**	**1.41**	**2.17**	**1.00**
%	**14.48**	**49.77**	**8.36**	**12.91**	**5.94**

The weights and ratios of different parts of banana were determined in order to determine the ratios at which they will be loaded into digesters in order to maximise the use of all the residues. From table 2 it can be noticed the high percentage of stems (almost 50%) compared to other parts of banana tree.

Results of raw material analysis

Table 3 summarises the results from the analyses of raw materials

Table 3 Results of different parameters analysed in raw material

Parameter	Stem	Leaves	Peels	Cow dung
Dry matter (%)	6.67	26.88	25.58	17.2
Humidity (%)	93.33	73.12	74.5	82.8
Ash (%)	9.09	16.67	18.87	-
Volatiles matter (%)	90.91	83.33	81.13	-
C (%)	35.4	51.3	51.6	41.70
N (%)	1.1	1.1	0.5	1.40
C/N ratios	32.18	46.64	103.20	29.8
P (ppm)	300	1125	1400	743.75
Na (ppm)	580	540	550	-
K (ppm)	72900	23100	44400	15200
Ca (ppm)	18700	21400	9500	62200
Mg (ppm)	3000	7300	4200	-
Fe (ppm)	510	304	420	-
Mn (ppm)	150	660	100	-
Zn (ppm)	110	64	76	-
Cu (ppm)	4	6	4	-

The results of analysis of banana tree residues show that the stems contain less dry matters than the peels and the leaves. In all the cases the results are higher than the optimal values of the literature which recommends between 5 and 10% of dry matters for a continuous fermentation. C/N ratio is also high for the leaves and the peels but it is normal for the cow dung and the stems. The recommended C/N ratio ranges between 20 and 30 [6].

To adjust these two important parameters, a dilution with water was carried out. As far as cations are concerned, their contents are far lower than the thresholds of inhibition [6].

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The trends of volume of biogas produced and temperature

Figure 3 exhibits the trend of the total volume of biogas produced

0
20000
40000
60000
80000
100000
120000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
A 5 days period
Average volume of
biogas produced (mL)
Dig I
Dig II

Figure 3 The biogas total volume trend

The gas starts to appear one day after the loading. As this gas was not combustible, it could be simply the air entered during the loading. During 5 days which followed the loading, the gas was combustible only after removal of CO_2. If the trend of the curves is considered, we note that Dig II knew a normal fermentation with a progressive rise from the 2nd period (the 6th day of biogas production); it is from this day that the gas is perfectly combustible and from the 50th day (10th period) the quantity of biogas starts to regress. The pick of fermentation appears after 40 days approximately. As for Dig I, one notes that it did not follow a normal fermentation. Indeed, a small quantity of biogas was produced after 40 days for a period of 30 days. This difference could be explained by the contribution of cow dung in the Dig II which, being a source of nitrogen, contributed to adjust the C/N ratio. During a period of 79 days (experimental retention time), the total volumes were 142749 mL for Dig I and 733898 mL for Dig II. The temperature remained in the mesophilic range during all the experiments and did not know enormous fluctuations. This shows that the results obtained can be reliable at least with regard to the influence of the temperature. The mean temperature was 37.4^oC.

Productivity calculation

From the total volume and the retention time another important parameter, productivity has been calculated as indicated in Table 4.

Table 4 Productivity of the two laboratory digesters

Parameter	**Digester**	
	Dig I	**Dig II**
A : Dry matter (Kg)	1.79	2.72
B : The quantity under fermentation (Kg)	37.7	43.1
C : Total volume of biogas (mL)	142749	733898
D : Retention time (Days)	79	79
E = C/D : Mean production (mL/d)	1806.95	9289.84
$C \times 10^{-6}/A$: Productivity (m^3/Kg DM)	0.0797	0.2698
$E \times 10^{-6}/B \times 10^{-3}$: Productivity ($m^3/m^3/d$)	0.0479	0.2155

The productivity, expressed in m^3/KgDM, is a significant parameter because it accounts for the production capacity of biogas by a given biomass. When it is expressed in $m^3/m^3/d$, it is related to the digester and shows its output of biogas per unit of volume expressed as m^3. Comparing the data obtained with those of the literature, we find that the

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productivity of banana residues (269.8L/Kg DM) is comparable to that of trees leaves which is 252 L/KgDM and is far higher than that of the sole cow dung which is only 205 L/KgDM[6]. The value of 0.2155 $m^3/m^3/d$ is also comparable with that of the literature which is 0.2 to 0.5$m^3/m^3/d$ [6;11].

Evolution of the biogas composition

The biogas composition in methane and carbon dioxide is expressed as mean percentage for each period of 5 days on Figure 4.

0
10
20
30
40
50
60
70
80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
A 5 days period
Mean biogas composition (%)
CO_2-DigI
CH_4-DigI
CO_2-DigII
CH_4-DigII

Figure 4 Biogas composition trend for the two digesters

The profile of biogas composition is a normal trend for the second digester (Dig II) whilst Dig I exhibits an irregular biogas production. Hence the biomethanisation succeeded in

Dig II. Indeed, a normal fermentation is characterised by a progressive increase in CH_4 and a progressive decrease of CO_2 with time. The mean composition of biogas and its heating value were also calculated as it appears on Table 5.

Table 5 Mean composition and heating value of biogas

Mean biogas composition and heating value	**Dig I**	**Dig II**
Mean CO_2 (%)	41.4	41.93
Mean CH_4 (%)	58.6	58.07
Calculated heating value (kJ/m^3)	21,845	21,647

The mean biogas composition in methane achieved with banana tree residues (58.07% for Dig II and 58.6% for Dig I) is similar to that of tree leaves (58.07%), to that of sole cow dung and to that of maize stalks (59%) [6;12].

pH trend

The pH trend of the biomass under fermentation as a function of time is presented on Figure 5. It can be noted that the pH remained almost unchanged. The literature estimates the optimal pH for fermentation between 6.8 and 7.5. For values lower than 6.8 there is an acid inhibition and over 7.5, an ammoniacal inhibition [6;12]. However, Dig II which gave a better yield, exhibits values which slightly exceed those of the literature. One can thus consider that the bacteria can always be active in an interval of +/−0.1 or even 0.2 units of pH.
Indeed, the maximum of production was recorded between the 30th and the 45th day when the pH raised from 7.40 to 7.68. As for Dig I, its low yield would not be ascribable to the pH

because it is always close to neutrality. The causes are thus to seek elsewhere in particular in the C/N ratio.

5
5.5
6
6.5
7
7.5
8
0
1st
day
1 2 3 4 5 6 7 8 9 10
Weeks
pH
DigI
DigII

Figure 5 The pH trend of the biomass under fermentation

Effluent analyses

Table 6 Results of effluents analyses

Parameter	Digester	
	DigI	DigII
pH-H_2O	7.2	8.78
pH-KCl	6.58	7.85
C (%)	45.9	40.1
N (%)	2.7	2.3
NH_4^+ (mg/l)	49	58
NO_2^- (mg/l)	4.4	4.6
NO_3^- (mg/l)	35	40
P(ppm)	2125	2150
K(ppm)	16500	34600
Ca(ppm)	23200	34500
Mg(ppm)	8300	13500
Na(ppm)	980	1780

The results from the analysis of the effluents are encouraging in the case of Dig II since they are similar to those obtained for the cow dung alone. Indeed, the effluents of the dung of cow contain 2.3 to 4.7%N, 0.9 to 2.1%P, 4.2 to 7.6%Ca and 0.6 with 1.1%Mg [11].

Assuming that the soil requires the maximum of nutritive elements, one hectare needs 33Kg N, 11Kg P and 48 kg K [12]. The results out of the present study show that if an $8m^3$ batch digester is considered, the quantity of the effluents obtained is 8 tons which contain 184 kg N, 17.2 kg P and 276.8 kg K. These contents largely exceed those which are proposed for one hectare. Reference made to phosphorus which is often a limiting element, we note that its content is almost twice higher that the recommended one.

Conclusion and recommendations

During this study the objectives were met. Indeed, from banana tree residues, biogas and a fertilizer of good quality were produced. The results obtained on the productivity and the effluents show that the biomethanisation of these residues can be exploited on a large scale, especially in rural area of Rwandan where banana constitutes the main cash crop.

However it was found that banana tree residues cannot be expected as a source of biogas alone; an animal biomass, cow dung in this case, has to bee mixed with them. In particular, this study contributed to reduce the use of cow dung for the production of biogas since 5 to 7 cows are needed to make function an $8 m^3$ biogas plant running on cow dung alone[12] whilst the introduction of banana residues reduces the numbers of cows to 2, *i.e.* a reduction of 60 %. Finally it can be noticed that, although this study contributed a lot to the reduction of the quantity of cow dung, it cannot guarantee that the technology of biogas will be easily popularized in Rwanda where building materials are still very expensive. Therefore another study on alternate building materials to bricks and cement, materials currently used, would be

of a great importance. Another study on the applicability of the results at large scale and for a continuous type of digesters has to be carried out also.

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STUDIES ON ALCOHOL PRODUCTION FROM SWEET POTATO

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Abstract

There is nothing new in the use of alcohol made from root crops as a motor fuel. Alcohol is an excellent alternative motor fuel for petrol engines. The reason alcohol fuel has not been fully exploited is that, up until now; gasoline has been cheap, available, and easy to produce. However, nowadays, crude oil is getting scarce, and the historic price difference between alcohol and gasoline is getting narrower. Alcohol fuel can be an important part of the solution for Rwanda because there is tremendous scope to use bulk production of sweet potato into alcohol. The total sweet potato production in both seasons is found to be 1,607,296 tones/year. The average productivity of Sweet potato in the country irrespective of seasons is found to be 8.9 tones/ha. If all of the available agricultural surplus were converted to ethanol, alcohol would supply less than 5% of motor fuel needs.

There is a need for alternate use of sweet potato because it cannot be stored for longer periods without decay. This study has the specific objective of producing local beer from sweet potato and to test the alcohol content of it. The study reveals the fact that the alcohol production from sweet potato increases up to 48 hours of fermentation thereafter the alcohol content decreases, though the fermentation is continued. It is found that the average alcohol content in 24, 48 and 96 hours of fermentation of sweet potato malt yields 13.0, 13.2 and 12.80 % of alcohol.

INTRODUCTION

Currently there is a big push to find and develop alternative sources of energy so that dwindling reserves of crude oil and other fossil fuels may be conserved. As Edward Teller[4], one of the America's leading physicists points out: "No single prescription exists for a solution to the energy problem. Energy conservation is not enough. Petroleum is not enough. Coal is not enough. Nuclear energy is not enough. Solar and geothermal energy are not enough. New ideas and developments will not be enough by themselves. Only the proper combination of all of these will suffice", it showed the importance of alcohol extraction as a fuel for engines in Rwanda.

Alcohol fuel can be an important fuel for Rwanda because there is tremendous scope to use bulk production of sweet potato into alcohol. If all of the available agricultural surplus were converted to ethanol, alcohol would supply less than 5% of motor fuel needs. The most important aspect of this 5% is it can be renewed each year, and each litre of alcohol produced will save a litre of petroleum oil.

Sweet potato is widely grown in Rwanda as a food crop. Sweet potatoes contain average about 22% starch and 5-6% sugar for a total of 27-28% fermentable material. A tonne should yield up to 182 Kg of alcohol. Sweet potatoes are cooked and converted in a manner similar to potatoes with the exception that they contain only about 66% water and some dilution is necessary. Sweet potato contains saccharine (sugar) materials in which the

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carbohydrate (the actual substance from which the alcohol is made) is present in the form of simple, directly fermentable six and twelve carbon sugar molecules such as glucose, fructose, and maltose. Hence, sweet potato has the potential for alcohol production.

REVIEW OF LITERATURE

There is nothing new in the use of alcohol as a motor fuel. Mathewson[1] stated that when Nikolaus Otto invented the internal combustion engine, gasoline was not available. Ethyl alcohol at 180-190 proof was the specified fuel. The model "T" Ford was designed to run on the available crude gasoline, alcohol, or any combination of the two. Kusmayanto [2] stated that there are two kinds of biofuel derived from crops, i.e ethanol and biodiesel. Ethanol can be produced from any grain, root, tubers, fruits containing fermentable carbohydrates. Mays [3] experimentally found out that sweet potato can yield alcohol of 5821 litre/ha from the crop yield of 462 tonnes/ha.

MATERIALS AND METHODS

Cooking of sweet potato

The sweet potato is cleaned with water to remove the soil and other foreign materials. It is cut into small pieces and put inside the cooking vessel. Water is added at the rate of 100 ml for every 200 gm of sweet potato. It is cooked well in the electrical stove. Cooking is accomplished by heating the mixture of sweet potato and water to a slow boil and holding at this temperature for 30-60 minutes. Generally, the mash is sufficiently cooked when it is soft and mash. During cooking, it is stirred well.

Water for dilution of mash

Dilution is simply the addition of water to adjust the amount of sugar in the mash or the amount of alcohol in the beer. It is necessary because the yeast, used later in the fermentation process, can be killed by high concentration of alcohol. Also, during the mashing and conversion of starchy material, dilution is necessary to make the mash easier to stir and handle. The object of dilution is to end up with a beer of 10% or more alcohol when fermentation is complete. The dilution of water with the mash prepared is 400 ml for the 200 gm of sweet potato.

Mash Cooling

After cooking, the content is diluted with water. It is allowed for cooling in the same container. The temperature recorded is 45°C. At this temperature of mash, yeast is added. The amount of yeast added is 2 gm in the diluted mash prepared.

Fermentor

A glass flask of one liter capacity is taken as a container for fermentation of the mash. The cooked, cooled, diluted mash with yeast is transferred into the fermentation container for microbial action on starch and saccharine materials in the mash.

Rotating distillation unit

Rotating distillation unit consist of a stationery electrical heater. On the top of the heater, a closed glass beaker is placed. This beaker is filled with the fermented mash of sweet potato and yeast. This beaker is made to rotate by a electrical motor fitted in the system. The beaker is also connected with a cooling tower, which is also made of glass. Cold water enters inside the cooling tower, it cools the alcoholic vapor and get the heat from the vapour. There is a continuous flow of cold water entering into the cooling tower and exiting as hot water from the tower is also arranged. The glass beaker containing the fermented mash is heated to a temperature 78°C by means of a temperature controller. It is the boiling point of

alcohol. The vapour thus produced is condensed in the cooling tower and then the vapor is converted into a mixture of alcohol and water. This mixture is collected separately.

Hydrometer

A hydrometer is a device used to find out the density of a mixture of water and alcohol. It is a little float with calibrated stems used to measure the density of the mixture of
liquid of water and alcohol. The alcohol content of the mixture can be obtained from the
standard two way table plotted with temperature and density of the mixture..

Fig 1: Hydrometer used to measure the density of a mixture of alcohol and water

An electronic balance was used to measure the weight of sweet potato to prepare the cooking
material for mash. A sieve of hole size less than 1 mm is used to filter the fermented mash
of the sweet potato to separate the waste materials and the beer.

Experimental layout for alcohol distillation from sweet potato

The beer produced from sweet potato in different periods of fermentation is taken up
for finding the alcohol content. The experimental layout is shown below for easy under
standing.

Table 1: Experimental layout for distillation of Beer prepared from Sweet potato

Fermentation Stages	Replication	Fermentation hours
S1	R1	24
	R2	24
	R3	24
S2	R1	48
	R2	48
	R3	48
S3	R1	96
	R2	96
	R3	96

Note : S- stages of fermentation, R - replication of the experiments

Beer produced in 9 different experiments with different periods of fermentation are distilled
to find out the alcohol content. The flow chart for the alcohol production from sweet potato is
given below:

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Fig 1: Flow chart for preparation of alcohol from sweet potato

Alcohol content from standard tables.

The beer produced from the sweet potato is distilled in the rotating evaporation type distillation unit. Alcohol is evaporated at the temperature of 78°C. The alcoholic vapor is cooled by a circulating cold water tube around the vapors. The condensed vapor is collected in the form of distilled alcohol in a container. Alcohol thus produced also has water content. The amount of alcohol collected is measured and water is added to make it 100 ml. The density of the mixture is found out by a standard hydrometer. The temperature of the mixture is found out by means of a accurate thermometer. When the temperature and density of the mixture is known, the alcohol content is found out by using a standard table. The standard table is a two way table containing the density of alcohol water mixture and the temperature of the mixture, which gives the alcohol content. The standard table to find out the alcohol content is given in Annexure.

RESULTS AND DISCUSSIONS

Area of cultivation and productivity of sweet potato in Rwanda

Table 2 brings out the fact that the mean productivity of sweet potato in different parts of the country in Season - A is 11.5 tonnes/hectare and 6.3 tonnes/hectare in Season - B. The average productivity of sweet potato in the country irrespective of seasons is worked out to be 8.9 tonnes/ha.

Table 2: Area of cultivation and productivity of sweet potato

Province	Season - A			Season - B		
	Cultivated area, Ha	Production, tonnes	Productivity, tonnes/ha	Cultivated area, ha	Production, tones	Productivity, tonnes/ha

Byumba	10761	112780	10.5	6888	64564	9.4
Cyangugu	4643	68636	14.8	6762	34826	5.2
Gikongoro	6783	63165	9.3	8160	30525	3.7
Gisenyi	7066	39614	5.6	11424	35330	3.1
Gitarama	14687	117438	8.0	14259	117499	8.2
Kibungo	8580	127701	14.9	9350	66926	7.2
Kibuye	6551	65206	10.0	6490	32756	5
Kigali	11508	195541	17.0	11495	115076	10
Ruhengeri	8883	116084	13.1	11669	57740	4.9
Mean	8829.1	100685	11.5	9610.8	61693.6	6.3

Source : MINAGRI (Rwanda Development Indicator)

Alcohol content of sweet potato beers in different fermentation period

Three replications for 24, 48 and 96 hours of fermentation of sweet potato based beer is carried out to find out the alcohol content. Alcohol produced in 9 different experiments with different periods of fermentation are distilled to find out the alcohol content.

The sweet potato beer of nine samples each weighing 250 ml is produced in the laboratory. Three samples are fermented for 24 hours, the second three samples are fermented for 48 hours and the third three samples are fermented for 96 hours. Data is tabulated in Table 3.

Table 3 reveals the fact that the average alcohol content in 24, 48 and 96 hours of fermentation of sweet potato malt yields 13.0, 13.2 and 12.80 % of alcohol. It is also found that the alcohol content increases up to 48 hours of fermentation thereafter the alcohol content decreases. The reason assigned for increase of alcohol content initially is due to more microbial activity and its multiplication, which consumes the sugar and starch in the beer and produces more and more alcohol. After 48 hours, the feed material present in the beer is almost consumed up by the microbes, there is not enough feed material for further microbial activity, the microbes becomes dormant or it may die for want of sugar and starch or it may consume some alcohol.

Table 3: Alcohol content of sweet potato in 24, 48 and 96 hours of fermentation time.

Fermentation time (Hours) and replications	Distillate collected ml	Dilution with water, ml	Density after dilution, gm / cc	Temp. ° C of diluted mixture	Density of 99% pure Ethonol gm / cc	Alcohol % .in 250 ml sample taken	Alcohol %.in diluted distillate
24 Hours							
R1	80	20 (80/100)	0.960	22	0.780	31.92	12.7
R2	60	40 (60/100	0.960	18	0.780	33.48	13.4
R3	82	18 (82/100	0.960	23	0.780	32.18	12.9
Average alcohol content in 24 hours of fermentation, %							13.0

48 Hours
R1 80 20
(80/100
0.960 19 0.780 33.22 13.3
R2 75 25
(75/100
0.960 20 0.780 32.96 13.2
R3 70 30
(70/100
0.960 21 0.780 32.69 13.0
Average alcohol content in 48 hours of fermentation, % 13.2
96 Hours
R1 85 15
(85/100
0.960 21 0.780 32.69 13.0
R2 90 20
(80/100
0.960 23 0.780 32.18 12.8
R3 90 10
(90/100
0.960 24 0.780 31.92 12.7
Average alcohol content in 96 hours of fermentation, % 12.80

SUMMARY AND CONCLUSIONS

The study revealed the fact that Rwanda has total cultivated area of sweet potato in both season A and B is 175,592 ha/year and the total sweet potato production in both seasons is found to be 1,607,296 tonnes/year. The mean productivity of sweet potato in different parts of the country in season-A is 11.5 tonnes/hectare and 6.3 tonnes/hectare in season-B. The average productivity of sweet potato in the country irrespective of seasons is worked out to be 8.9 tonnes/ha. Hence; there is a need for alternate use of sweet potato because it cannot be stored for longer periods without decay. The alcohol production from sweet potato showed the fact that the alcohol content increases up to 48 hours of fermentation thereafter the alcohol content decreases. It is found that the average alcohol content in 24, 48 and 96 hours of fermentation of sweet potato malt yields 13.0, 13.2 and 12.80 % of alcohol.

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Finding Solutions to Lighting Problems for the Rural Poor.

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Key Words: Rural Light demand, Local Turbine manufacturers in informal sector, LED technology, Affordable Pico and Micro Hydro Projects.

Abstract

This paper discusses how technological advancement and its adaptation by the informal sector has given birth to a revolutionary solution to lighting problems for the rural poor. Thomas Edison's seemingly forward-looking statement that "we will make electricity so cheap that only the rich will burn candles" was true enough for the industrialized world, but it did not anticipate the plight of 1.6 billion people—more than the world's population in Edison's time—who 100 years later still have no access to electricity. Due to population growth, barriers to electrification, poverty and other factors, Edison's dream has remained a dream that until now seems un-surmountable. Estimates by the World Bank show that only two percent of rural Sub-Saharan Africans have access to "modern energy" and electricity. That means at least 500 million people do not. Lighting has been a primary need for the rural

areas whose use of fuel from outdated lighting technology typically comprises up to 15 percent of a person's annual income.

The informal sector has been very active in trying to meet this need which has been ignored by the formal sector. To realize this demystification of technology as the reserve for western very sophisticated plants has been necessary. Entry to the informal sector by engineers and technicians has led to the development of affordable technology to generate electricity and distribute it to the rural. This includes the manufacture of affordable small water turbines and wind mills.

New Technological advancement in White Light Emitting (WLED) which consumes very little energy and can light for more than 50,000 hours now makes electricity affordable to the poor. Small electricity projects can now reach up to ten times more people. By manufacturing affordable wind and water turbines and use of WLEDs Edison's dream will become a reality for the rural poor.

Introduction

Thomas Edison's seemingly forward-looking statement that "we will make electricity so cheap that only the rich will burn candles" was true enough for the industrialized world, but it did not anticipate the plight of 1.6 billion people—more than the world's population in Edison's time—who 100 years later still have no access to electricity. Due to population growth, poverty, barriers to electrification, and other factors, the International Energy Agency projects that this number will decline very gradually (by less than 1% per year!) between now and the year 2030.

This paper takes a look at the lighting problems faced by the rural households. It focuses on solutions that our company "Clean Air Energy Solutions" has been researching and implementing, that we believe will enable this group to start benefiting from electricity

using renewable energy. It demonstrates how the informal sector can reduce the cost of
electricity generating equipment to make them more affordable and how when combined with
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advancement in lighting technology the solution is on hand. It also addresses other viable
energy solutions that the electricity generated can be used for when it' s not fully utilised for
lighting. It lays its emphasis on lighting as we feel the large energy needs for heating and
cooking can best be met using other renewable energy solutions such as Biogas and Biomass
using energy efficient cookers and heaters.

Lighting in the Households

The major sources of lighting for rural households in Kenya and most of Africa South
of the Sahara are kerosene and firewood. According to a sturdy conducted by the Kenyan
Ministry of Energy in year 2001 on Kenya' s demand, supply and policy strategy ; -

· Kerosene is used by approximately 94% of rural households for lighting.
· .The annual per capita consumption of Kerosene at the household level is 90 Litres.
· Electricity only reaches 3.8% of the rural households in Kenya mostly near the large
towns.

Kerosene has been for a long time been the more reliable lighting source for the rural
households. Above sturdy also show that although one in four people today obtain light
exclusively with kerosene, candles and biomass they receive only 0.1% of the resulting
lighting energy services. As an illustration of the inefficiencies involved, users of kerosene
lighting in Africa pay 600 times more per unit of useful energy services than do those in
electrified homes with incandescent lamps in Europe.

The International Energy Agency estimates that, in aggregate, the fuel-based lighting
costs the world's poor $38 billion each year, plus ~190 megatons of CO2 emissions, the most

important greenhouse gas. This does not even include the costs for candles and batteries.
Efforts to address the issue clearly have immense potential benefits for equity, development,
and the environment.
Kerosene lamps emit significant amounts of Carbon monoxide and unburned hydrocarbons. This courses indoor pollution, which is hazardous to human health. This is
particularly detrimental to school children who must sit very close to the lamps to read. The
combustion of one litre of Kerosene produces about 2.5 kg of Carbon dioxide (1). Acute
respiratory infections ranked fourth in the share of the burden of diseases in sub-Saharan
Africa (accounting for 7% of the total) (2).
The cost of fuel has recently escalated to prices that most of the rural poor can no
longer afford. Those who have school going children are forced to use up high percentages of
their income for kerosene increasing poverty in the rural areas. Unfortunately due to
increased demand for electricity and exhaustion of large scale hydro potential sites the Kenya
Electricity Generating Company has become increasingly dependent of diesel driven generators raising the cost of grid electricity tremendously. Small generator sets using fossil
fuels have also been popular with imports to Uganda between 1993 and 1997 of estimated
total capacity of about 69,955 Megawatts (3).
Presence of good sources of light improves livelihood of the population and makes it
possible for households to increase their working hours beyond daylight. Affordable clean
energy services will improve the income and health of the households hence reduction of
poverty.

Alternative Clean Lighting Solutions.

Electricity is produced mainly from hydropower in most of Africa South of the Sahara
However sites with large potentials are quickly running out and alternatives have to be
explored. Geothermal energy has become an important source for electricity especially in

Kenya with an installed capacity from Olkaria II of 64MW and Olkaria III of a further 64MW. However, its exploitation is very expensive and it' s only tapped by use of expensive

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technology to supply the main grid. Solar lighting from photovoltaic panels for charging batteries have also become popular with the more affluent rural households but the use is still limited to less than 0.15% of the households due to high initial installations cost of about US $ 625 for a 50 Wp PV System (4). Wind energy has not been used for lighting to any significant degree in the region because of installation cost being very high compared to energy produced from fossil fuels. However with the enormous increase in fossil fuel costs and the resulting green house gas emissions its use is also increasingly becoming viable.

Africa and the Middle East annual wind energy potentials is estimated at 76,000 Terawattshrs of which 16% is realizable (5).

Barriers to Rural Electrification.

The most important barriers to promotion in rural electrification have been high initial investment costs of renewable energy technologies and inadequate financial intermediaries.

Connection to the grid is very expensive for the rural poor who are mainly located far from the grid. Electricity demands by industries and the urban area already outstrips the local hydro electricity supply with most of the large hydro-power potential sites having already been exploited. Current alternatives include geothermal which is very expensive, and utilization of hydro power from sites with potentials lower than 1000kW. These sites have previously not been exploited as they were deemed to be expensive and uneconomical due to cost of small water turbines and distance from the main grid.

Solutions to Rural Electrification Barriers

The popularisation of small hydro-power plants in Kenya especially by Intermediate

Technology Development Group (ITDG) has raised a lot of interest by the informal sector in this sector. Through its training about four companies are successfully installing affordable hydro power solutions in Kenya. This has been made possible by availability of information on Micro-Hydro design and locally made equipment.

Project cost for Small Hydro power projects

Using simple but reliable civil works and locally manufactured water turbines coupled with high quality but affordable alternator, electrical control systems and affordable distribution systems that meet regulatory standards most projects are achievable through contributions of about US $ 3.57 Per watt that the beneficiary receive from the projects. Pico and Mini Hydro Electricity projects have been criticized as not feasible as they produce very little amounts of power, are far from the main grids and that the cost per watt is high compared to large hydro power projects. However the value of return is much greater because beneficiaries only require very small amount of electricity basically for lighting, large populations normally live near the sites and can be connected using simple mini grids, Initial Connection fees to the main grid is more expensive than contributions for a small hydro project, cost of power after installation is very low as compared to current Kenya Power and lighting tariffs.

Connection to the main grid in Kenya costs US $ 570 with minimum monthly charges of about US $ 14. Fuel levies have recently doubled the electricity costs in Kenya. Most of the rural poor are unable to raise the installation charges and many of those who do are normally disconnected after a short period due to the very high cost of grid electricity. The comparison below reveals that grid electricity is beyond the reach of the rural poor households as its capital cost is almost 3-5 times their annual income. Renewables, however, are more affordable as they cost a fraction of the annual household income.

Table 1.

Affordability Analysis of Grid Electricity, Solar PV & Pico-hydro by the Poor

	Grid Electricity	**Solar PV**	**Pico-Hydro minigrid serving 110 households (1.1kw)**	**Pico-Hydro minigrid serving 110 households (2.2kw)**
Annual Household income (US $)[1]	818	818	818	818
Capital cost per Household Incl. internal wiring $ fittings(US $)	2360-3840	325	56	54
Capital cost per Household as a % of annual household income	289-469%	40%	7%	7
Total upfront cost per household (US$)	2,393-3873	398	162	151
Total upfront cost as a % of annual household income (US$)	293-473%	49%	20%	18%

Source: Kenital, 2003 (6); Maher, 2002a & 2002b (7); ITDG, 2004 (8); Institute of Economic Affairs/Friedrich Ebert Stiftung, 2002 (9); UNDP, 2001 (10); Republic of Kenya, 200a (11).

[1] Only applies to household income in the Kirinyaga District where the two pico-hydro projects are installed. Comparatively, household income is estimated to be US $ 1,825 deriving from the US $1 per capita per day threshold; approximately US $ 1800 (2002) based on National GNP; and, about US $ 957.

Pico-hydro

Ndima Pico-hydro power project (ITDG)

Located near Kerugoya in Kirinyaga District of Central Province this project was installed in 2001 to produce 3kW for a mini grid to supply 100 homes with lighting. The total cost of the projected is estimated at US $ 70,000 with service lines to 100 homes. It is now more than six years old since supply started in 2002 and serves 150 members with very few members being permanently disconnected since. Each household can use three 7 watt energy saver bulbs all lighted during the peak hours. Using LED lights each homestead can now use 6 lights of 1.5watt each and have a radio or a low watt Television operating at the same time.

Membership can be increased to 200 homes with the use of LED lights. Other uses of the energy during of peak hours includes use of electric equipment for processing animal feeds, lighting and heating for chicken at night, a barber shop and security lighting for the community.

This project was made possible by member contributions from the community of US $ 300 with the balance being met by ITDG and the ministry of Energy. The community has been able to maintain the project through monthly payments of US $ 3. Benefits have included clean energy for lighting, Radio, Television and for food processors. Reductions have been seen in use of kerosene, diesel, dry cells and battery charging from grid power as illustrated below.

The project is currently being upgraded by the community to increase the output to better serve the beneficiaries. Other projects have also been developed in the area with a Micro-Hydro project producing 14kW situated only 1km up stream. The success of these projects prove that they are viable and indeed cheaper than the large projects and have minimum ecological impacts are they are mostly runoff the river projects.

Table 2

Energy Source	**Pre-electrification average expenditure (Kshs.)**	**Post-electrification average expenditure (Kshs.)**	**Percentage decrease (%)**
Kathamba Pico-Hydro Installation			
Lighting			
Kerosene	340	94	72
Candles	62.5	0	100
Entertainment (radio & TV)			
Battery Charging	90	0	100
Dry Cells (non-rechargeable)	241	93	61
Thima Pico-hydro Installation			
Lighting			

Kerosene 323 149 54
Candles 33 0 100
Entertainment (radio & TV)
Battery Charging 146 75* 49*
Dry Cells (non-rechargeable) 207 66 68
Source: Adapted from Balla, 2003 (13)

Locally Manufactured Water Turbines

Manufacture of affordable high quality turbines with efficiency higher than 75% has been made possible by: -

- The availability of simple high quality designs
- Experienced personnel in the informal sector
- Availability of materials required.

However, the lack of foundries that can manufacture turbine bodies and runners restricts the fabrication of some types of turbines that would be best suited for some of the sites.

Locally manufactured turbines are priced at about 70% less than new imported turbines and 40% less than reconditioned imported turbines. Most Pico to Micro-Hydro sites require custom made turbines and they are not only expensive to import but they also take about 8 months before delivery. Availability for readymade turbines for Pico, Micro and Mini Hydro projects is also very limited as most sites have unique characteristics which make uniformity very hard. Quantities required are also very small for large manufactures locally and abroad to be interested in. Imports from Asia are also more expensive than locally made turbines and of less quality. Local manufacturers are also able to support their turbines better as compared to distant manufactures where cost of returning the equipment or receiving parts is expensive and takes long.

High quality efficient Cross flow, Pelton, Kaplan and Reversed Pump turbines can now be fabricated at affordable prices locally. Fortunately most of our local sites can be served very well by the two types. Turgo, Francis and Kaplan turbines are hard to fabricate to precision that would result to good efficiency. Francis turbines would be applicable for sites with high volumes of water with low heads that would not be served by the Pelton or

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Crossflow turbines. This makes it necessary and thus the need for foundries that would manufacture high quality reaction runners and cylindrical sophisticated bodies.

Technology Advancement in Lighting – WLED

Fig 4.

Light Comparison Table

Lamp Type	**Homemade Kerosene**	**Incandescent**	**Compact Fluorescent**	**WLED**
Efficiency (Lumens/Watt)	0.03	5-18	25-50	90-110
Rated Life (Hours)	Supply of kerosene	1,000	6,500 - 15,000	50,000 to 100,000
Durability	Fragile and dangerous	Very fragile	Very fragile	Durable
Power consumption (Watt)	0.04 - 0.06 Litres/hour	45W	7W	2W
CCT deg K	1,800 deg.	2,652 deg.	4,200 deg.	5,000 deg
CRI	80	98	62	82
$ after 50,000 Hours	$1,251	$175	$131	$20

Source: Light Up The World, 2007 http://www.lutw.org/techapproach.htm, Philips Lumileds Lighting Co.

New advancement in technology in lighting has recently improved efficiency in lighting using White Light Emitting Diodes (WLED). LEDs are diodes, which is a semiconductor device that will conduct electricity in only one direction. The device is fabricated from layers of silicon and seeded with atoms of phosphorus, germanium, arsenic or other rare-earth elements. The layers of the device are called the die and the junction between the materials is where the light is generated. The electricity enters from one side of the die and exits out the other. As the current passes through the LED device, the materials that makes up the junction react and light is emitted. Different materials and designs have different colored lights and intensities. LEDs are now bright enough to be considered for applications that traditionally use incandescent bulbs.

Technical advances have dramatically improved the reliability and the performance of the LEDs since they were invented in the 1960's. The lifetime for the well engineered new generation of LEDs is around 100,000 hours of use, or 30 to 40 years of normal operation. Because they are a semiconductor device, they are also very rugged and are not subject to fail when dropped or vibrated, as do incandescent and fluorescent lights.

The original LEDs only emitted light of one frequency or color of light. These were blues, greens, yellows, oranges or reds and they were unsuited for domestic lighting. Recent innovations in materials, doping and die structure have developed high brightness LEDs that emit light in all visible frequencies to produce white light.

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LED technology has developed rapidly with the achievement by Cree, Inc. (US) demonstrating a 65 lm/W commercial use light in September 2003 and a 131 lm/W by 2006 at 20 mA. Nichia Corporation has developed a white light LED with luminous efficacy of 150 lm/W at a forward current of 20 mA which will revolutionize the LED market if available in the market next year as planned at an affordable price. Curently the highest efficiency high-power white LED is claimed by Philips Lumileds Lighting Co. with a luminous efficacy of 115 lm/W (350 mA).

Some of the benefits that WLED give include: -

· LED’ s convert about 90% of the electricity into light. A 1 Watt LED Emits approx
100 Lumens as compared to Incandescent bulbs with only 17 Lumens to a watt and 50 Lumens for Compact Fluorescent tubes (6)

· LED’ s work at low and save voltage
· LED’ s generate very low heat thus efficient and save to touch.
· LED’ s Lasts about 100,000 hours about 5 years continuously without replacement
· No damaging Ultraviolet so they do not cause fading to artwork
· Not fragile or sensitive to shake
· Directional so emits higher percentage of light in the desired direction.
· Colored LED lights produce just needed colors thus no need for filtration

Table 5.

Conclusion

At an approximate cost of US $ 51 per beneficiary using LED bulbs, lighting for rural
poor is now feasible where Pico to Micro-Hydro sites are found. Solar and wind turbine minigrids
should also be feasible. Local manufacturing of affordable turbines and new technology
in lighting by use of White Light Emitting Diodes (WLED) has now made small hydro
projects viable and affordable to the rural households. Small hydro projects can now serve
many more beneficiaries than was possible before reducing each beneficiary’ s contribution.
By being able to extract some of the 65% hydro-potential that has been considered not
feasible the potentials of lighting the rural poor and also the increased input to the grid would
be massive. Development of affordable and efficient wind power generating equipment is the
new frontier and a challenge that when conquered a true solution for lighting for the rural
households will be in hand. Locally we have made no significant progress in the manufacture
of Solar lighting equipment and photovoltaic technology products are all imported. However

COMPARISON OF BENEFICIARY COST FOR A 10KW MICRO-HYDRO PROJECT

BULB TYPE
PROJECT
WATTS
BULB
WATT
S
4
BULBS
WATTS

TOTAL
BENEFICIARIES
PROJECT
COST [1]
US $
CONTRIBUTIO
N PER
BENEFICIARY
US $

Incandescent
bulbs 10,000 45 180 56 57,142 1000
Compact
Fluorescent bulbs 10,000 7 28 357 64,285 200
WLED 10,000 1.5 6 1,667 85714 51

Source: My own Estimates based on lumens per watt achievable from each technology.

[1] Estimated project cost increases by larger distribution system for increased beneficiaries.

the assembly of photovoltaic cells locally can drastically reduce the cost making it more affordable to the rural poor.

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Using wind energy for harvesting and providing sustainable safe groundwater for a Rural Community in the Masendu Ward in Zimbabwe.

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Key Words: Borehole, Environmentally friendly, groundwater, Wind energy, renewable energy

Abstract

Masendu Ward is a Rural Community in Zimbabwe with a population of approximately 16500. It lies in a semi - arid region with a low average seasonal rainfall resulting in a general water shortage. Unavailability of reliable water sources is a cause for concern which weakens the community to cope with development needs. This is exacerbated by the emigration of young people to neighboring countries in search of employment leaving the very young and very old to fetch water. This paper is an offshoot of a community intervention project funded by Kellogg Foundation through the Institute of Rural Technologies. It looks at harnessing the use of windmills as an alternative source of energy. The aim is to supply sufficient water to the Community by establishing suitable sites for boreholes and installing improved windmills. It highlights community involvement in the fabrication of the new windmill system. It is an experimental intervention study that results in water availability leading to community development and engagement in commercial activities. The project team designed and constructed a windmill with a 100% improved throughput and less material content on the wheel. Results pertaining to the improvement of windmill efficiency are an ongoing issue.

Introduction

A windmill is a machine that converts wind energy to usable energy through the rotation of a wheel made up of adjustable blades. It is an environmentally friendly way of pumping water which has been used for a long time. It does not require human power and uses wind a renewable source of energy. Most Rural communities in Zimbabwe are characterized by the unavailability of safe drinking water. While this is not prevalent in all rural areas, Masendu ward has such a problem that affects development of the community.

The ward is in the Bulilimamangwe Rural District in the Matabeleland South province of Zimbabwe. The ward consists of six villages covering nearly $42km^2$ with a population of approximately 16500 [1]. The villages together have a common problem of water shortage for domestic and agricultural activities. This is as a result of the ward being located in the semi-arid region that has a low average seasonal rainfall of 493mm [2]. It becomes prudent to alleviate the problem of water shortage by utilisation of technological means for groundwater abstraction. Wind energy was the main focus of progression to resolving the problem. Wind is a renewable resource that can be put to good use and in areas where there is no electricity, it becomes quite useful. In this development, the project team looked and encompassed skills transfer and capacity building for community members.

Statement of the problem.

There is a general water shortage in the ward to carter for domestic, livestock and commercial use. Boreholes have been sunk by the District Development Fund (DDF) and

these use manual hand pumps. Many have become dysfunctional due to various reasons.

Most youths have emigrated to neighbouring countries in search of employment leaving the very young and very old to fetch water from the manual hand pumps. A survey of the community has indicated that there is a perceived aquifer in one of the villages (Luvuluma).

Windmill power is an appropriate alternative for driving pumps required to draw water from boreholes to the surface, especially considering that there is limited electricity supply in the ward and the use of hand pumps is laborious.

Hypothesis

The people in the community are convinced that there is an underground aquifer in Luvuluma village and that can be a source of ground water. The wind blows all year round though at varying speeds and directions. This wind power can be utilized for driving water pumps. There are 3 windmills in the ward and these are not properly working due to lack of maintenance and spare parts.

Aim and Objectives

To utilize wind energy to provide consistently sufficient safe water supply to the Masendu community simultaneously capacity building local cadres.

In order to achieve this, the project team will focus on the following areas

- To establish the extent of water shortage and provide a solution to the problem using appropriate technology.
- To design, manufacture, install and commission windmill pumps and related water reticulation infrastructure at suitable sites.
- To train the community in maintaining and repairing windmill equipment.
- To, through research, acquire knowledge in renewable energy utilisation.

Study Design

This study is two fold as it is experimental and interventional. Experimental in that it involves the assessment of current windmill technology and formatting efficiency improvements. It is interventional in that while the research is being done, the community requires water supply and hence the current technologies are utilized to urgently intervene and provide water.

Theoretical framework

To benefit from appropriate technology, an efficient energy supply system is required. Several energy sources including electricity, hand pumps and windmills have been employed for pumping water. Electricity is expensive and is therefore not an option for most rural communities (e.g. Masendu) in the developing countries. Wind energy is an economic alternative source for pumping water where wind conditions are reliable. A windmill is a machine that converts wind energy into usable energy through the rotation of a wheel made up of adjustable blades, [3] and has been in existence since A.D. 500. This method is efficient, does not require human power, is environmentally friendly and is cheap [4].

Windmill with a drive mechanism that incorporates gears has been found to be durable [5]. In 1886, Thomas Perry designed the aerodynamic multi-bladed windmill [6], which is in

common use in Zimbabwe. The use of windmills in Zimbabwe has deteriorated, as they seem to have inherent faults. The gear box that converts rotational motional into vertical reciprocating motion fails often and hence rendering them unusable a few years after installation.

Water consumption was found to be significantly correlated to explanatory variables such as "household size" and "age of the household's head" [7]. With these variables, water consumption can vary from 100-170litres per person per day [7]. The Masendu community has varying household sizes and livestock. Some villages engage in gardening activities while others do brick moulding. All these factors affect water consumption.

Sandstones characterize Masendu area and this type of geology is known to be very high yielding in underground water. Studies in the Nyamandhlovu-Tsholotsho areas that lie to the north of Masendu ward [8] as well as areas around Bulawayo [9] with a similar geological outlook have shown high groundwater potential. Oral discussion with community members have shown that Luvuluma village lies on top of an aquifer that stretches from Nyamandhlovu and boreholes in that area have good yields at an average depth of 50 meters.

Methodology

The methodology used directed effort towards provision of water to the community as

an urgent intervention while at the same time making improvements and research comparisons on boreholes pumped by electric pumps with those pumped by windmills.
Interviews were conducted with community members with each village providing two representatives to be part of the research team. These representatives were given questionnaires to establish water requirements for their respective villages.
A survey visit was done to the Provincial headquarters and the district offices of the District Development Fund (DDF) in Gwanda and Plumtree respectively. The aim of these visits was to establish the number and status of boreholes and the challenges that the DDF is facing in repairing and maintaining existing boreholes.
Windmill manufacturers were visited and the researchers' engineering intervention was intended to improving the durability of functionality and efficiency of the windmill system.
Masendu Central village houses a cultural centre for the ward that is going through major development. At this cultural centre there is a small fabrication workshop doing a commercial activity in the area. As part of capacity building, the researchers were working together with two key members of this cooperative for skills transfer and capacity building.
Members of this cooperative have no formal qualification in fabrication or business management. Fabrication work is done by semi-skilled workers. Furthermore various community cadre teams collaborated with the Institute of Rural Technology (IRT) research team other than the cooperative members referred above.
42

Results

The results are presented under the ensuing subheadings thus;

Water demand survey

Table 1 below shows the estimated population, used to derive the water demand, in the ward by village. Water consumption per person each day was pegged at an average of 100 litres.

Table 1 Ward Water demand survey by village

Village	(Estimated population)	Number of Boreholes

Water yield per village at average of 2000l/hr per borehole
Estimated daily Water demand (litres /day)
Water deficit per day in each village

Masendu Central (3600)
8 128,000 360,000 -232,000

Thandawani (3000)
1 16,000 300,000 -284,000

Tjeboroma (3200)
1 16,000 320,000 -304,000

Mambo (2400)
7 112,000 240,000 -128,000

Luvuluma (2000)
Not established 200,000 -200,000

Makumbi (2300)
Not established 230,000 -230,000

TOTAL 1,650,000 -1,378,000

The ward has an overall water demand in excess of 1,650,000liters each day. This demand is compared with the current capacity of installed boreholes giving a daily water deficit of 1,378,000litres per day for the ward. It is important to note that at this stage, the demand estimation excludes water demand by livestock and gardening activities. The research looked at the borehole distribution and calculated an estimate of the output that is expected per day. This is on the assumption that each borehole has a yield of 2000liters per hour and pumping is done 8 hours a day. Information in Table 1 considers water from all boreholes noted as supply for the ward. This is considered with the background information that some of the boreholes in the ward have salty water and have not been abandoned.

Ward Water points Audit

An audit of the current number of boreholes in the ward was conducted. Table 2 shows a breakdown of the boreholes distribution in the six villages, the record of boreholes sited by the IRT team and intervention work done.

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A survey of the villages showed that the boreholes are distributed regardless of the population distribution and this leaves some homesteads in the villages more exposed to water shortage than others. The IRT team pegged and facilitated drilling of some boreholes in the ward as indicated in the table above.

In view of the ward setup and population of people and boreholes, the research team did an analysis to establish the adequacy and need of water in the water. This paper is an offshoot of a project to provide water in all the villages. What has been done to date is only a step towards provision of sustainable water sources for the ward at large. No work has been done in Mambo and Makumbi villages as the team has not started work in these villages. The pilot project was set for Masendu Central, Thandawani and Tjeboroma villages.

Table 2 Village Water points distribution

Village	**Number of Boreholes**			**Comment**
	Current / In existence	**New sites pegged /surveyed**	**Drilled this project.**	
Masendu Central	8	6	1	Complete drilling and installation of electric pump on 1 site, where water is already being drawn.
Thandawani	1	1	1	Complete fabrication and installation of windmill and tank for garden irrigation and livestock watering. Has a dam, which supplies more water although it quickly dries out.
Tjeboroma	1	2	1	Drilling complete and windmill fabrication in progress.
Mambo	7	0	0	Boreholes quickly dry out due to alleged lack of adequate ground water
Luvuluma	No. not established	3	1	1 flushed unsuccessfully
Makumbi	No. not established	Yet to be		

surveyed
and pegged
0 No work was done by the IRT
researchers in this village.

District Development Fund (DDF) Operations

DDF has a water infrastructure maintenance team that is based in the ward. It is however currently not fully equipped and hence not attending to maintenance of boreholes in the area. This results in the exacerbation of the water shortage problems in the ward. An interview with the District water engineer at DDF revealed the following problems.

- Knowledgeable workers who are experienced in borehole installations and maintenance have left the country.
- Due to the economic hardships in the country, DDF is currently under-funded hence has inadequate money to carryout repairs for the boreholes as necessary.
- There is a general shortage of spare parts so repair and maintenance activities cannot be completed.
- If underground pipes leak, DDF would remove and not replace the leaking pipe and hence the pumping cylinder would be above the water table and this result in the borehole quickly drying up.

Windmill design, fabrication and installation

The research team designed a windmill which takes from the traditional windmill with specific improvements for efficiency of use. The main improvements to note are on the wheel, gearbox and the supporting structure. The wheel of the windmill is a 3meter diameter one with blades made of reinforced 0.8mm galvanised sheets. This reduced the total weight of the wheel material translating directly to savings in material used. Other windmills in operation are made of 1mm-1.2mm galvanised sheets. The advantage to reduced weight in this way is that the windmill is capable to turn easily from slow wind speeds as compared to those with thick and heavier blades.

The gearbox for assessed windmill manufacturers in Zimbabwe from 3 main manufacturers have an average stroke length of 150mm. Our design influences a stroke of 300mm in a borehole cylinder of 900mm. This improvement gives a 100% increase in water throughput per wheel rotation.

There was also resulting and persistent bearing failure at the connection of the gearbox to the supporting structure and an improvement for use of thrust bearings reduces the number of failures. The main support structure was so designed to withstand all calculated forces while remaining economic for construction. As such the designed windmill offers a cost saving of 35% compared to other manufacturer’s windmills.

The picture in Fig.1 below shows the IRT water group team working on one of the windmill wheels in their workshop.

Figure 1. Nicholas Tayisepi and William Goriwondo holding the wheel in the workshop.

Each village in the ward will have a windmill/windmills installed. The water shortage in the ward can be alleviated by installation of water abstraction systems that use wind energy as a source of power. Apart from Masendu Central village and the cultural centre in particular, all other villages have no electricity. This gives use of Windmills an urge over electric pumps. The emigration of young people in the ward also gives windmills an urge of hand pumps as windmill power does not get tired as long as wind is blowing. In the same way, water would be pumped into storage tanks for use later when the wind is not blowing.

Windmill power whenever wind blows and storage tanks are not full would be used to pump water that would become available when required.

Challenges

Promoting the use of new technology in developing countries face a major challenge in that the deserving communities will be requiring urgent assistance and research takes time to deliver. As in this case, there was a push to have water for the communities; all recommendations and findings were not implemented as at present though these would be implemented at project completion. This cause a problem in developing countries for the use of appropriate technology would be delayed.

This project was conducted in a hyperinflationary environment which made it difficult and caused a lot of distortions. The challenges appeared throughout the life cycle of the project.

Community level challenges

The community have cadres that are responsible for Water and Sanitation as well as others that are responsible for Infrastructure development. These were attached to the project and would be expected to perform manual work together with the project team. As this was a voluntary exercise, team members lost interest along the way as they did not recognise with the project. 4 cadres were selected to work with the research team together with 3members from Bazose cooperative. Of the 7 members, only 4 consistently worked with the IRT research team. The other 3 disappeared and hence did not benefit from the intended skills transfer and community capacity building.

Material and services supplies

As this was an experimental project, the Bill of Materials would be largely dependent on the final quantities. This was not the case since the project was also interventional with the need to urgently provide water to the community. The hyperinflationary environment compounded the problem. This meant that all quotations given by suppliers would be valid for 24hrs. The project team was not responsible for procurement and by the time the orders are placed, materials prices may have gone up or may have been sold out. This presented a great challenge for the researchers. You are always rushing to have materials procured effectively while they are still available.

Conclusion

There is a significant shortage of water in the ward which warrants great improvement in the water supply situation. The IRT research team set to replace the use of hand pumping with an improved type of windmill and this would provide a facility for water storage as opposed to collecting just enough when hand pumping is in use. An improvement to the windmill structure and gearbox was done and this is intended to replace the traditional manual pumping of water and hence improvement to irrigation at Thandawani garden. On completion all the target areas will have improved water supply. Capacity building and skills transfer was achieved as Bazose cooperative members and community cadres were trained on-the-job during the project. These would be available to attend to regular maintenance and minor repairs of windmill pump systems. Future work in the ward involves the possibility of totally providing for infrastructure to meet the total water demand of all households in the ward and their anticipated development needs. Lack of access to a reliable source of water impedes community development as community members spend lots of time abstracting water.

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Estimation of Global Solar Radiation in Rwanda using Empirical Models

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Abstract

Understanding solar radiation data is essential for modeling solar energy systems. The purpose of the present study was to estimate global solar radiation on horizontal surface using sunshine-based models. Angström-type polynomials of first and second order have been developed from long term records of monthly mean daily sunshine hour values and measured daily global solar radiation on horizontal surface at Kigali, Rwanda. Coefficients of those polynomials were derived using least square regression analysis. These coefficients were then used for the estimation of solar radiation in other places of Rwanda where measures of solar radiation do not exist but sunshine records are available.

Introduction

While Rwanda has adequate solar energy potential to support its energy demand, it is therefore important to harness that resource in view to find solution to energy shortage and environmental degradation the country is being faced to. Solar energy is now considered to be the most effective and economic alternative resource [10]. In developing countries, such as Rwanda, interest in solar energy applications has been growing in providing electricity and water supply in rural areas. Understanding solar radiation data is essential for modeling solar energy systems. Solar radiation is used directly to produce electricity for photovoltaic (PV) systems and solar thermal systems. Therefore, precise knowledge of historical global solar radiation at a location of study is required for the design and estimation of the performance of any solar energy system.

In Rwanda, quite few stations have been measuring the daily solar radiation on a consistent basis. Geostationary satellites give estimates of incident radiation on large regions (1° by 1° or larger grid-cells) but their non-precise historical databases have limited applications for local studies [5], [9]. In the absence and shortage of reliable solar radiation data, hence, it is necessary to approximate solar radiation by the use of empirical model in order to estimate and predict global solar radiation. These models use historical meteorological data of the location under study. Empirical models are classified in three categories: sunshine-based models, temperature-based models and cloud-based models [4], [6], [8], [11]. Recently some studies on modeling solar radiation have been done in Rwanda [2], [7], but yet comparative studies on techniques used and results are still needed.

In this work, Angstrom-type polynomials of first and second order have been developed for approximating the global solar radiation in Rwanda from a long term records of monthly mean daily sunshine hour values and measured daily global solar radiation on horizontal surface at Kigali International Airport station, Rwanda. Correlation coefficients obtained from the least square regression were then used to estimate solar radiation at locations where only sunshine records were available.

Data and methods

Data

In Rwanda, recorded global solar radiation data on horizontal surface were obtained for only one station located at the International Airport of Kigali (Lat: 01° 58S, Lon: 030°

08E, Alt: 1,490m). The remaining primary surface weather stations are recording daily temperature, pressure, relative humidity, precipitation, wind speed and direction, and sunshine duration. While the secondary stations (not mentioned in the present study) are recording temperature, pressure, relative humidity and precipitation. Data were provided by the Department of Meteorology in the Ministry of Infrastructure (Rwanda). Table1 presents the locations of stations and the period of observation for which global solar radiation R_G and sunshine duration S were measured.

Table1: Location of stations and period of observations of global solar radiation and daily sunshine duration.

Station	**Altitude**	**Latitude**	**Longitude**	**R_G**	**S**
Kigali	1,490m	$01^o58'$ S	$30^o08'$ E	1984-87	1971-now
Butare	1,760m	02° 36' S	29° 44' E	-	1988-93
Kamembe	1,591m	02° 28' S	28° 55' E	-	1988-99
Gisenyi	1,554m	01° 40' S	29° 15' E	-	1986-93
Gikongoro	1,930m	02° 29' S	29° 34' E	-	1990-99
Kibungo	1,680m	$02^o10'$ S	$30^o32'$ E	-	1990-92

Description of the model for the estimation of solar radiation

The global solar radiation reaching the earth's surface is made up of two components, direct and diffuse. Direct radiation is the part which travels unobstructed through space and the atmosphere to the surface, and diffused radiation is the part scattered by atmospheric components such as gases molecules, aerosols, dust and clouds.

At the top of the atmosphere, extra-terrestrial solar radiation, also known as Angot radiation (Whm^{-2}/day^{-1}) can be calculated using the following expression:

sin sin)

360

) cos cos sin 2

365

24 (1 0.033cos(2

$_{0}\ _{0}\ \omega\ \ \phi\ \ \delta$

π

$\phi\ \ \delta\ \ \omega$

π

$\pi \quad {}_{s\,s} R = I + J +$ (1)

Global solar radiation reaching the Earth’s surface can be estimated by empirical models when measured data are available. The simplest model commonly used to estimate average daily solar radiation on horizontal surface is the well-known Angström equation [1], [3]:

( )

0

1 2

$_0 S$

S

R

$R_G = \alpha \;\; + \alpha$ (2)

Angström had suggested values of 0.2 and 0.5 for empirical coefficients $_1 \, _2 \; \alpha$ *and* α respectively.

In the present study, Angström model was compared to a second degree polynomial function of monthly average daily sunshine hours of the form:

2

0

5

0

3 4

0

( ) ( )

S

S

S

S

R

$R_G = \alpha \;\; + \alpha \;\; + \alpha$ (3)

49

Results and Discussion

Linear and polynomial least square regression techniques were developed based on equations (1), (2) and (3), and observed global solar radiation at Kigali International Airport station. The computed values for the coefficients of regression are 0.2416 $_1\,\alpha$ = , 0.6411 $_2\,\alpha$ = , 0.0696 $_3\,\alpha$ = , 1.3261 $_4\,\alpha$ = , $\alpha_4 = 1.3261$, 0.6674 $_5\,\alpha$ = − .

The linear Angström equation is then given by:

0.2416 0.6411( )

$_0 S \; _0$

S

R

$R_G =$ + (4)

And the second degree polynomial function is given by:

2

$$R_G = R_0\left[0.0696 + 1.3261\left(\frac{S}{S_0}\right) - 0.6674\left(\frac{S}{S_0}\right)\right] \quad (5)$$

Values of R_G (4) and R_G (5) corresponding to the estimated global solar radiation respectively with equations (4) and (5) are presented in Table2 and are compared to the measured values R_{Gobs}. The deviations between the estimated and measured values given by R^2 (%), RMSE (%) and MBE (%) are presented in Table3. The poor correlation observed in Figure1, Figure2 and Table2, during the rainy season period (November to April) is probably due to large differences in the characteristics of the sky during this period. Nevertheless, the two models are slightly in good agreement with the observed data, and hence they can simply be applied to estimate monthly average daily global radiation from monthly average daily sunshine hours, which are available in primary stations across the country. The results in Table4 give an annual solar radiation of 5269 Wh/m2/day for Rwanda while the commonly given value in literature or web site is 5.15 kWh/m2/day. In [7], the monthly value obtained by the authors using a non linear meteorological radiation models (MRM) with satellite data was varying between about 4.3 and 5.2 kWh/m2/day. In the present study in Table3, the minimum value for the station of Kigali (R_G (4) = 4942 Wh/m2/day, R_G (5) = 4960 Wh/m2/day) occurs in May, while the maximum value (R_G (4) = 5721Wh/m2/day, R_G (5) = 5738Wh/m2/day).

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Figure1: Least square linear regression and polynomial regression between R_G/R_0 and S/S_0

Figure2: Comparison of Global solar radiation and estimates of global solar radiation from equations (4) and (5) at International Airport station of Kigali.

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Table2: Comparison between the observed global solar radiation R_{Gobs} and estimation of global solar radiation from equations (4) R_G (4) and (5) R_G (5) at the station of Kigali.

Month	R_{Gobs}	R_G(4)	R_G	RE(4)	RE(5)
Jan	5211	5311	5315	-1.91	-2.00
Feb	5156	5473	5483	-6.15	-6.34
Mar	5339	5336	5326	0.06	0.25
April	5067	5055	5043	0.24	0.47
May	5267	4942	4960	6.16	5.82
Jun	5461	5472	5469	-0.20	-0.14
Jul	5664	5680	5652	-0.28	0.21
Aug	5722	5721	5738	0.02	-0.27
Sep	5544	5525	5557	0.35	-0.23
Oct	5367	5447	5457	-1.49	-1.67
Nov	5042	5114	5079	-1.43	-0.75
Dec	5356	5161	5151	3.63	3.81
Annual	**5350**	**5353**	**5352**	**-0.06**	**-0.05**

Table3: Values of R_2, RMSE (%), MBE (%)

Model	R_2	RMSE (%)	MBE (%)
Linear	0.8893	2.78	-0.062
Polynomial	0.8911	2.77	-0.054

Table4: Annual values of the ratio S/S_0, extraterrestrial solar radiation R_0, estimate of Global solar radiation R_G in Rwanda, and the ratio R_G/R_0.

Station	Annual S/S_0	Annual R_0 Wh/m2/day	Annual R_G Wh/m2/day	Annual R_G/R_0
Kigali	0.477	10098	5335	0.53
Butare	0.502	10164	5488	0.54
Kamembe	0.414	10150	4937	0.49
Gisenyi	0.454	10067	5196	0.52
Gikongoro	0.507	10152	5529	0.54
Kibungo	0.446	10119	5131	0.51
Average	**0.466**	**10125**	**5269**	**0.52**

Rwanda, being a small country but with difference in terrain at different locations, the computed coefficients $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ obtained by least square regression techniques have been used to estimate global solar radiation at places where there is no equipment to measure that quantity but sunshine duration has been measured.

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Figure3: Estimated Global Solar Radiation for the five studied sites

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Figure4: Monthly average of estimated global solar radiation on the sites of Rwanda

Conclusion

The empirical Angström-type linear model and a second degree polynomial model both based on sunshine duration have been studied in this work. The two models were compared with the data collected on the site of Kigali International Airport station. From the comparison of the results of these models it was observed that the estimated were in good agreement with the observed data and the two models were slightly similar. This has led to choose one of the two models to be applied for all stations of Rwanda where measures of sunshine duration exist but facilities of recording global solar data do not exist. The estimated data can further be used in the design and estimation of performance of solar systems in Rwanda.

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Nomenclature

Astronomical quantities and solar quantities

)sin(2 (284) / 365)
180
= (23.5 π + *J*
π
δ : Solar
Declination (radian)
J=1,365, Julian day
=) × *Latitude*
360
(2
π
ϕ : Latitude at the place (radian)

$\omega_s = arc\cos(-\tan\phi\ \tan\delta)$: Sunset Hour Angle (radian)

$\pi = 4.0 \times \arctan(1.0)$

$I_0 = 1367\,Wm^{-2}$: Solar Constant

R_0: Extra Terrestrial Solar Radiation (Whm^{-2}day^{-1})

$\bar{R}_0$: Monthly Average Daily Extra Terrestrial Solar Radiation (Whm^{-2}day^{-1})

R_G: Daily Global Solar Radiation on horizontal surface (Whm^{-2}day^{-1})

$\bar{R}_G$: Monthly Average Daily Global Solar Radiation on horizontal surface (Whm^{-2}day^{-1})

$S_0 = \frac{2}{15}\omega_s\frac{180}{\pi}$ = Day Length

$\bar{S}_0 = \frac{2}{15}\omega_s\frac{180}{\pi}$: Monthly Average Day Length

S: Daily Sunshine Hours

$\bar{S}$: Monthly Average Daily Sunshine Hours

Statistics quantities

$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$: Coefficients of regressions

$Qmes_i$: Measured quantity

$Qest_i$: Estimated quantity

$\overline{Qmes} = \frac{1}{N}\sum_{i=1}^{N} Qmes_i$: mean of $Qmes_i$, $i = 1, N$

$\overline{Qest} = \frac{1}{N}\sum_{i=1}^{N} Qest_i$

N
Qest
1 1
1 : mean of *Qest i N* $_i$, = 1,
$\sum$ $\sum$
$\sum$
– –
– –
=
( )$_2$)$_2$
( ) ( )
Qmes Qmes Qest Qest
Qmes Qmes Qest Qest
R
i i
i i :
Correlation coefficient between $_i$ *Qmes* and
$_i$ *Qest* quantities
R^2 : Coefficient of determination
N
Qmes Qest
RMSE
N
i
i i $\sum$ =
–
= 1
( )$_2$
: Root Mean
Square Error
Qmes
RRMSE = *RMSE* : Relative Root Mean Square
Error
N : Number of observations
55

DESIGN OF A COMBINED SOLAR ENERGY SYSTEM FOR A REMOTE FLUX TOWER AND A RURAL COMMUNITY

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Key words: Solar Energy, Flux Tower, Rural Electrification, RETScreen®, Photovoltaic

Abstract

In this paper, we report on the design and proposed implementation of a solar photovoltaic (PV) system to power a rural community in conjunction with the development and implementation of a PV system to supply a flux tower for remote weather monitoring sited adjacent to the village. The flux tower is part of the broader NASA African Monsoon Multidisciplinary Analysis field campaign and funding for the tower PV system is being leveraged to support the needs of the community who will be the de facto caretakers of the remote, infrequently visited flux tower. The design of the system was based on the estimated power needs for the FLUX tower combined with that of the village community. Community need was defined after a meeting including the village chief, community members and students and faculty of Howard University who were part of the project. The community understood that the design was constrained by the budget allocation for the flux tower PV system, but nevertheless engaged in discussion about their needs and arrived at a consensus, where community members agreed to allocate at least one light bulb for one room in each village house, lights in two toilets and two kitchen areas and two power outlets accessible to all villagers. The system was designed utilizing RETScreen®, a free software[1], applying their PV System modules. The output from RETScreen demonstrated the need for two sets of PV arrays, one to support demand from the village and the second to support the FLUX tower instruments. For the village system, an inverter was required to enable villagers to utilize AC, while the FLUX tower system was routed directly through a charge controller to the batteries, and all instruments, which were DC powered. The entire project was conducted using students enrolled in independent study elective courses. The paper provides some background on solar energy and discusses the rationale with particular attention to a wind-powered alternative. The

design output for system implementation from RETScreen® is presented and the appropriateness of the technology selection is discussed.

INTRODUCTION

Especially in the African context, the development and implementation of alternative, decentralized energy generation systems is imperative for development to occur in a sustainable way. Using large centralized power generation facilities to feed electricity to rural and remote communities and locations is expensive and non-viable in Africa away from the major cities, primarily due to the lack of a well-dispersed electric grid. The benefits of utilizing renewable energy technologies as the basis for decentralized energy generation have been discussed at length in the popular and professional press and need not be re-stated here

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[2]. It is sufficient to reiterate that continued use of non-renewable fossil fuels is resulting in increased green house gas (GHG) emissions and attendant increased drivers for climate change. Hence, implementation of a solar energy system serves the purposes of both providing energy to communities previously without power and to do so without contributing to any increases in GHG emissions.

The energy situation in Senegal, as in much of sub Saharan Africa, is critical with very low rates of rural electrification, rising from 5% in 1998 to only 9% by 2003. The national grid, shown in Figure 1, generated about 514 MW in 2003, the bulk of which was thermoelectric (448 MW) with an additional 66 MW from hydroelectric power [3]. Senegal faces the usual problems of having to import the entire fossil fuel requirement for its thermal power plants, while facing massive deforestation as rural communities and the poor have only forest-based biomass to use as fuel. Rural electrification used to be based on the

extension of existing networks and installation of diesel power generators; however,
increasing energy costs and the need to address GHG emissions are forcing governments to
look for de-centralized systems that utilize renewable and alternative energy.
Successive governments have undertaken rural electrification projects which resulted
in 558 electrified localities by 2000, but this is less than 8%. The government views rural
electrification as a **powerful tool to reduce poverty and has** created the Agence Sénégalaise
pour L' Electrification Rurale [4] whose mission targets a 30% rural electrification rate by
2015.

Figure 1: Electric Grid in Senegal [1]

Figure 2:Senegal and Kawsara [1]

Kawsara

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Decentralized alternative energy systems include solar, microhydro, geothermal, wind and
biogas, amongst others [5]. The selection of the appropriate alternative energy technology
follows heuristics that have been established before, such as the SHTEFIE‡ analysis for
technology selection, which weighs various factors, including social, technological, and
financial considerations, in the final selection of the appropriate technology. Given the
Senegalese situation, there is abundant sunshine, on average 8.5 hrs of sunshine per day, and
solar energy becomes an option. Annual solar radiation is estimated at 2.18MWh/m_2, enough to
provide electricity to all Senegal, had the government the resources to harness that energy! The
major drawbacks, including large initial capital outlay costs, availability of solar PV panels, and
efficiency of panels, are serious and substantive hindrances to the widespread adoption and
implementation of solar energy system. **Solar** *energy* has been used in many traditional
technologies for centuries, and has come into widespread modern use where other power

supplies or connection to a central grid are absent, such as in remote locations and in space.
While traveling through the atmosphere 6% of the incoming solar radiation (insolation) is
reflected and 16% is absorbed resulting in a peak irradiance at the equator of 1,020 W/m^2 [6].
Average atmospheric conditions (clouds, dust, pollutants) further reduce insolation by 20%
through reflection and 3% through absorption. Many technologies have been developed to make
use of solar radiation. Some of these technologies make direct use of the solar energy (e.g. to
provide light, heat, etc.), while others produce electricity. Specific direct-use technologies
include solar hot water systems that use sunlight to heat water, Trombe walls that passively heat
by channeling heated air into ventilation system while storing heat in a thermal mass which can
be radiated in the evening, and a solar box cooker, which traps the sun's energy in an insulated
box and which has been used for cooking, pasteurization and fruit canning. Solar cells, also
referred to as photovoltaic cells, are devices or banks of devices that use the photovoltaic effect
of semiconductors to generate electricity directly from sunlight.
Although solar energy has many benefits, it should be remembered that solar electricity
tends to be expensive compared to grid electricity. Solar heat and electricity are not available at
night and may be unavailable due to weather conditions - thus energy storage technology or
complementary power systems are required. Solar cells also produce direct current (DC) which
must be converted to alternating current (AC) when used in currently existing distribution grids,
which usually incurs an energy loss of 4 - 12%. New 50 watt solar panels cost about $4.25 a
watt, or around $212 for a 50 watt panel, in quantity. For 120 watt panels, the cost is $700, or
$5.83 per watt. For an average urban middle class residence, a robust solar electric system will
cost about US$20,000.
Wind may provide a potential alternative, although the average wind speed at the

Senegalese location may not be high enough to sustain sufficient wind power generation Wind power is harnessed through turbines rotating through the force of wind on large blades, and the turbine is usually placed on top of a tower over ten meters high to capture wind at that altitude.

These wind towers are usually built together on “wind farms” that are large scale and can feed into the general grid. However, small individual turbines can also provide electricity to rural residences or grid-isolated locations. Wind energy is plentiful, renewable, widely distributed, clean, and releases no toxic atmospheric or greenhouse gas emissions.

Selection of a suitable site is key to the success of wind energy. Power available from the wind is a function of the cube of the wind speed, which means that, all other things being equal,

‡ Please see http://www.lboro.ac.uk/well/resources/technical-briefs/49-choosing-an-appropriate-technology.pdf

a turbine at a site with 5 meters/second (m/s) winds will produce nearly twice as much power as a turbine at a location where the wind averages 4 m/s. Good wind resource assessment is critical.

In general, winds exceeding 5 m/s (11 mph) are required for cost-effective application of small grid-connected wind machines, while wind farms require wind speeds of 6 m/s (13 mph). For applications that are not grid-connected, these requirements may vary, depending on the other power alternatives available and their costs. Drawbacks to wind energy include intermittent or inconsistent wind, some communities consider them an eyesore, and they can negatively affect bird migration patterns and pose a danger to the birds themselves. In the early 1980's, when the first utility-scale wind turbines were installed, wind-generated electricity cost as much as 30 cents per kilowatt-hour; now, state-of-the-art wind power plants are generating electricity at less than 5 cents/kWh, and costs are continuing to decline as more and larger plants are built and advanced technology is introduced.

PROJECT BACKGROUND

As part of the NASA African Monsoon Multidisciplinary Analysis (http://www.joss.ucar.edu/amma) field campaign, a remote weather monitoring station was established in the village of Kawsara (Figure 2), about 50 km outside Dakar. Faculty and students from Howard University (HU) participated in the NAMMA field campaign, allowing students and scientists to make measurements in Senegal to characterize bulk properties of mesoscale convective systems. Data being acquired include wind speed and direction, cloud shapes and contents, rainfall rates, temperature, humidity, and atmospheric pressure, all of which provide informational input into models of weather patterns over western Africa and how these influence hurricane formation. A 10-meter flux tower has been established at the site and faculty from Universite Cheik Anti Diop (UCAD) and HU developed a plan to leverage NASA support for a solar-powered remote flux tower to also provide minimal power requirements for the Kawsara village community, who would be the care takers of the flux tower site.
In June of 2007, two faculty members and two students conducted an assessment site visit to Kawsara. During the visit, students were first introduced to the principles of alternative energy systems in general with specific focus on wind and solar based energy generation.
Students also received lectures on the energy situation in Senegal in general and Kawsara in particular. This was followed by introduction to the RETScreen® software§ including the modules on clean energy systems, green house gas emission reduction calculations, wind energy and photovoltaic solar energy systems. Following two days of lectures and demonstrations, students were taken to the Kawsara Village community where the Flux tower placement site was located.

Energy Needs Assessment

At the village, students met with the community and the village headman where the project was explained and discussed. It was agreed that the current situation would be surveyed and then the minimum expectations and provision established. The village community had never had a connection to the central grid. There was a diesel generator that had either been purchased or provided, but there were no funds to purchase diesel fuel to run the generator, so this equipment lay in dis-use, rusting, in a shed. When it was purchased, rudimentary wiring had been put in place for two light bulbs and a power socket. Some members of the community also had cell phones, but they had no socket which they could use as a charge point. Discussion of the lighting situation lead to the agreement to provide one light bulb to each dwelling, a light

§ RETScreen® is a free software available for download from http://www.retscreen.net and provides complete textbooks and training manuals for diverse renewable energy applications.

bulb in two of the common toilet rooms (see Figure 2A and B) that were present in the village and two light bulbs where there was a communal kitchen area.

Figure 2A: A house in Kawsara, Senegal Figure 2B: Two toilets in the village.

Table 1 shows lights and power that would be supplied to the village and the various individuals and families in the community, showing the final outcome of the evaluations and discussion with the community and village Chief and what was agreed upon.

Students drew up the plan with the location of each light bulb and outlet and then the plan was shown to the villagers who agreed with the number, distribution and location of the light bulbs and power supply points. The needs assessment also provided the necessary inputs

TABLE 1: KAWSARA VILLAGE SITE SURVEY ON JUNE 27, 2007

HOUSE INDOOR OUTDOOR TOILET

EXISTING EXPECTED EXISTING EXPECTED

13 W Bulbs 13 W Bulbs 7W Bulb

Abdoulaye 3 3 1

Cowboy 2 1

Baisall 2 1

Common Cooking 1

Rassoul 3 2
Fall 2 2 1
Maribout 4 2 2
Chief 3 1
House 8 4 1
House 9 4 1
House 10 4 1
TOTAL 20 17 9 3 2
TWO ADDITONAL OUTLETS 300W TO BE INSTALLED IN COMMUNITY AREAS
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into the RETScreen® analysis software as the solar system configuration was designed and
developed.
Flux tower energy requirements were also supplied as input into separate runs of the
RETScreen PV module. The designs that resulted from both these evaluations are presented
in the following section.
Design for Village
The system configuration for the village resulted in a total need of forty-nine (49)
13W light bulbs with a total wattage of 637W, two (2) 7W light bulbs and two (2) 300W
power outlets. All of this is AC requirements, resulting in the total AC wattage for village
community of 1251W (= 637W + 14W + 600W). Usage of three (3) hours per day is assumed
with the result of total wattage hours per day of 3,753 Watt-hrs. For all such solar systems,
installed battery capacity will depend on the number of days of autonomy assumed. For the
village, the team assumed three (3) days of autonomy, requiring total battery capacity of
22518 Watt-hrs. The battery bank size can be computed from the ratio of the battery capacity
to the chosen battery voltage. Using 12V batteries, the battery bank size is 1,876.5 Amp-Hrs.
The typical rating for a 12V battery is 105 AmpHr so that the total number of batteries
required for the village would be [Number of Batteries = Battery Bank Capacity / 105
AmpHr] which results in a requirement of nineteen (19) batteries.
Number of Solar Panels
For the solar panels, investigations in the market revealed that a 130W 12V solar

panel was available off the shelf with no delays in shipping and delivery. The number of solar panels required can thus be calculated with knowledge of the amount of sunlight per day and the total Watt-hrs required. The calculated watt-hr requirement is 3,753 W-h. Using 120W panels and assuming 8 hours of sunlight, the number of panels required is calculated as twelve. However, after factoring in the efficiency of the solar panels, only about 5 to 6% of the incoming solar radiation is converted to electricity. Thus, accounting for the efficiency, we would need sixteen (16) panels, which can be arranged in two rows of eight (8) panels each, as shown in Figure 3 below. The RETScreen® software performed all the computations once the site location was entered along with the energy requirements.

Inverter Size

Since the rural community would require alternating current (AC) for its applications, the direct current (DC) from the panels and battery bank will be routed through an inverter so that the entire wattage for the village is AC. Since the total wattage hours are 3753W-hr for three hours daily, two 2,000W inverters will satisfy systems requirements.

Design for Flux Tower

The flux tower is comprised of various meteorological instruments, all of which run on direct current (DC). The instruments and there power requirements are show in Table 2. It is estimated that the radiometer, sonic anemometer, data logger, humidity/temp probes, and soil probe will be a total of 3 amps. Operation will be continuous at 24hrs every day.

The total current requirement for the flux tower instrumentation is 5 amps, and with a voltage utilization of 12V, the total power requirements are 60 Watts 24 hours per day, corresponding to a total of 1440 Watt-Hrs. For this system, the battery capacity to provide three (3) days of autonomy can be computed for a battery with nominal voltage of 12V and a rating of 105 AmpHrs, and the calculation yields a requirement for six (6) batteries, which will be connected in parallel.

TABLE 2: FLUX TOWER INSTRUMENTS

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· Sonic anemometer = 1 amp (24 hr)
· net radiometer = 1 amp (24 hr)
· data logger = 1 amp (24 hr)
· barometer = 0.2 amp (24 hr)
· humidity/temperature probe = 0.2 amp (24 hr)
· propeller anemometer = 0.2 amp (24 hr)
· carbon dioxide and water vapor gas analyzer = 1.2 amps (24 hr)
· ozone gas analyzer = 1.2 amps (24 hr)
· soil probe = 0.2 amps (24 hr)
· data acquisition = 3-4 amps (once a month for 1 hour)

Solar Panels:

For the flux tower, the solar panels are also assumed to be 120W 12V panels, and we assume 8 hours of sunshine per day. Based on the requirements and factoring in the efficiency, six (6) panels will be required, connected in parallel.

Discussion and Conclusion

Based on the evaluations and system calculations performed through the RETScreen ® software, this paper demonstrates the successful design and development of a solar supply system utilizing the RETScreen ® PV module. For the supply of energy to both the rural community and the flux tower, a total of twenty-two panels will be required. For the village, we will need twelve (12) 2V, 700 Ah batteries, and six (6) 12V, 105 Ah batteries for the flux tower. AC power for the village will be supplied through an inverter, while the DC power to the flux tower will be controlled through a 12V 30A regulator.

This project demonstrated the leveraging of a government funded scientific research project to support the development of a renewable energy system to satisfy needs of a rural community who until then had not had electricity. It also shows that engineering students can be engaged in appropriate technology projects as part of satisfying degree requirements in a manner that enhances student' s global social understanding and environmental sensitivity and

awareness. Finally, the paper provides a documentary record of a project that demonstrates the
successful design, development and proposed implementation of a PV-based system utilizing
RETScreen® software and the utility of the software as both a teaching and design tool.

Acknowledgments

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Figure 3: Eight (8) 120W 12V Solar Panels in
Series- Design for Village Solar Supply

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AN EXPERIMENTAL STUDY OF THE COMBUSTION CHARACTERISTICS OF LOW-DENSITY BIOMASS BRIQUETTES

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Key words: briquettes, briquetting, biomass combustion, solid fuels, stoves

ABSTRACT

In many parts of the developing world, wood is becoming a scarce resource. Densifying waste crop residues into biomass briquettes can provide an alternative household solid fuel, especially in rural areas. They can be manufactured industrially and on a small *rural scale using a simple hand-press, making them also very viable for poorer communities.*

Compared with wood, biomass briquettes are unique in that they provide opportunity to control in the manufacturing process the fuel density, moisture content, size and geometry. As well as the material properties, all these factors have been shown to have a significant effect on biomass burn rates. For a particular stove and cooking situation it is useful to be able to optimise the steady-state burn rate and minimise the emissions, improving efficiency and reducing exposure to smoke for those in the household. This paper forms part of a study seeking to better understand and later optimise biomass briquettes for different cooking situations. Here, preliminary results of a parametric study are presented for the variation of steady-state combustion rate with the density and geometry of a biomass briquette, burning in free air. Results are given for rectangular briquette slabs and for cylindrical briquettes with a central hole. A simple semi-empirical model is presented that explains the trend in the results. It is found that cylindrical briquette with holes burn faster than slabs with an equivalent surface area to volume ratio.

INTRODUCTION

Nearly half the world's population, almost all in developing countries cook using biomass solid fuels [1], predominantly wood [2, 3, 4]. With deforestation becoming a major problem in many parts of the developing world, there is increased scarcity of wood for household cooking. This especially affects remote rural communities that have no access to fuels such as liquid petroleum gas (LPG) and who depend substantially on burning collected local biomass for their energy needs [5, 2]. In regions of many developing countries it is not uncommon for women to spend more than 6 hours each day collecting and preparing the wood despite the fact that there are often vast quantities of waste biomass residues available with the potential to be used as fuel. Cooking is then often done over open fires, which are highly inefficient transferring only 5-10% of the fuel’s energy to the cooking pot.

Diminishing forest resources and increasing population make this a pressing issue and solutions are urgently needed, not only to meet energy demands in an environmentally friendly manner, but also to address pressing human health issues. In addition to their low efficiency, simple stoves such as the three-stone fire are smoky and are often used in enclosed spaces with limited ventilation, especially in the more wet tropical regions. Indeed, burning biomass such as solid wood fuels, cow dung and agricultural residues and coal is likely to be the largest source of indoor air pollution globally, and to the greatest extent in developing countries [1]. Open fires emit substantial amounts of pollutants, including respirable particles, carbon monoxide, nitrogen and sulphur oxides, and benzene. The small particles in woodsmoke can bypass the normal body defence mechanisms and penetrate deep into the alveoli of the lungs, harming the respiratory system and there have been clear links made between

their inhalation and disease [1]. These smoke problems particularly and considerably affect women and young children who, in developing nations are typically responsible for the domestic duties in the home.

In addressing these problems, much work has been done around the world on designing and optimising improved stoves with the aim of increasing combustion efficiency and improving thermal heat transfer to the pot. With the improved designs thermal efficiency can be increased to 25-30 %. These stoves, however, continue to use wood as a fuel. Biomass residues from agriculture and industry can provide an alternative to solid wood fuel. They can be found in abundance in many parts of the world, for example in Malaysia there are significant quantities of residues left over from palm nut processing [6], and in Ghana there are large quantities of sawdust residues produced by the timber industry [7]. On a rural level in developing nations, typically about 3-5 tons of agricultural residues are produced per acre [8]. Residues however, are often small in size when compared with solid biomass, burn rapidly with fluctuating power output and produce more emission products resulting from incomplete combustion. These conspire to make firewood the fuel of preference. They also have problems associated with their transportation and storage. This paper is part of a study exploring one option for solving the technical problems associated with residues by upgrading the biomass material by its densification into regularly shaped homogenous briquettes [6]. In this way the energy density of the fuel is increased, handling characteristics are improved [9], transportation is made more feasible and burn rate can be controlled [10].

Briquettes are not a new concept, in fact they are becoming well established in the field and there is a growing network of people manufacturing them on both rural and industrial scales. Notably an organisation called the Legacy Foundation in America has developed a low-pressure wet-briquetting process that uses a simple wooden press and has pioneered a successful training program for their production from crop residues aimed at rural communities in developing nations. The result has been the establishment of many small-scale briquetting enterprises that generate income and provide an alternative fuel for rural village communities [11]. The briquettes produced have a central hole, which is believed by many to improve the combustion characteristics of the briquette. This paper is part of a study in which the combustion behaviour of biomass briquettes is being experimentally investigated. The aim is to more rigorously understand the role of the central hole in combustion and to develop a simple semi-empirical combustion model that will predict the briquette burn rate.

Olorunnisola provides a good review on the manufacture of briquettes [9]. Various authors have studied the feasibility of briquetting different residues and investigated important parameters involved in briquette manufacture. This has involved the effect of compressive pressure, material moisture content, the time the material is in compression (dwell time), and binder content on briquette durability, mechanical strength, density, handling characteristics and the relaxation behaviour of the briquette when taken out of the mould [10, 9, 12].

Briquettes can either be burnt in woodstoves or in specially designed stoves. In terms of briquette combustion, the effect of density on the burn rate of briquettes has been investigated by Chin-Chin et al. [10]. Various authors have undertaken a proximate analysis for different biomass materials (for example [13, 6, 14]). Most combustion work relating to solid biomass is focused on wood. Kandpal shows that the burn rate of wood fuel in a stove has a significant effect on the stove’s thermal efficiency, and that there is an optimum fuel burn rate giving maximum efficiency for a given stove/pot configuration [15]. Being able to control fuel burn rate is therefore essential if we are to optimise thermal performance of any stove. The significant effect of fuel size on the burn rate has been observed by several authors

[16, 17], but there is not a parametric study of the effect of briquette geometry on the burn rate, which is essential to optimise briquettes for a particular stove and cooking situation.

This paper considers how briquette geometry affects burn-rate. In the methodology section the method of manufacture of briquettes of a consistent quality is described, followed by the set-up of the combustion rig and method used for measuring their burn rate. The results section presents the observed trends and fits a simple numerical model to the data. A discussion of these results ensues in the section on modelling briquette combustion, followed by some conclusions and a description of further studies that are planned.

METHODOLOGY

Briquette production

The manufacture of briquettes in more rural locations is of the central interest in of this study. It is possible to form briquettes from waste crop residues, in locations with limited equipment availability, using a wet process with a hand operated press [8]. In this study newspaper was chosen as the material for the briquettes, because it is readily available in the UK and bonds easily. Furthermore, because of its fibrous nature it is likely to behave in a similar way in the densification process to other fibrous organic residue matter, such as maize husks. It is this type of material that is more likely to be available for briquetting in rural locations.

The paper was soaked for at least 5 days and pulped in an industrial food-mixer. The briquettes were then formed by compression of the pulp into a mould with an Instron compression test machine using a range of pressures to achieve different briquette densities.

Different shaped moulds were used: a large rectangular mould and cylindrical moulds with a central solid cylinder passing through the centre along the central axis. The effect of pulp moisture content on the briquettes' final density was minimal; on compression water is squeezed out until an equilibrium reaction force is attained at a particular pressure.

After forming, the briquettes were oven dried at 105° C to reach 0% moisture content.

This was done to minimise the effect of this variable during these preliminary experiments because of the difficulty found in controlling moisture content. It should be noted that pyrolysis does not occur at this drying temperature. On removal from the oven the briquettes were then placed in a sealed container containing silica gel (which removes all the moisture from the air) and were allowed to cool to room temperature. All irregular parts of the briquette were removed from the edges. In order to produce briquettes of different surface area to volume ratios (A/V ratios), the large rectangular blocks were taken and cut with a band-saw into slabs of different dimensions and then oven dried again. The cylindrical briquettes were cut to the required heights and if required turned on a lathe to different diameters.

A stereometric method [18] was used to determine briquette density. This was chosen over displacement methods in order to ensure the briquettes, which would later be burnt, remained dry and were not structurally affected by the measurement. In this stereometric method the briquettes were weighed using a mass balance to a precision of ±0.01g. The dimensions of each briquette were measured using callipers as follows: For slabs, the height and width of the briquette were both measured by taking three approximately equally spaced positions along the edges and the mean calculated, the thickness was measured at each of the four corners of a slab and the mean taken: For cylindrical briquettes with central holes, the height was measured in four positions 90° to each other around the briquette, the external diameter of the briquette was measured in three positions, at the top, middle and bottom, the diameter of the internal hole was measured twice at each end in perpendicular directions. The volume of the nearest geometrical shape was then calculated and hence the density determined. Briquettes were then put back in the oven for a short time to drive off any atmospheric moisture that may have been absorbed and then transported in the sealed silica gel filled container to the combustion rig to be burnt immediately.

Combustion tests

In each test a single briquette was placed alone in the centre of a steel wire mesh grid resting on two supporting fire retardant bricks, allowing the free flow of air around the briquette. This was positioned on top of a mass balance (Metler tornado) interfaced with a PC to record instantaneous measurements of the mass every 10 seconds throughout the combustion process. Smoke was extracted using an extraction hood method [19]. The extraction rate was set so that it was sufficient to capture all smoke, but had no visible effect on a match flame held in the position normally occupied by the briquette. Ballard- Tremeer et al. [20, 19] have statistically shown, to a 95% confidence level, that such extraction rates have no effect on the burn rate.

Each briquette was ignited by placing a small amount of firelighter on a platform 4cm directly beneath, but unconnected to the mass balance. Enough firelighter was used to ensure the whole of the bottom surface of the briquette was ignited simultaneously, avoiding flame spread in the transverse directions. The firelighter was left in until the briquette was well ignited and had entered into its steady state burn phase. Mass loss was recorded every 10 seconds until the mass of the briquette was 5% of its initial mass. Mass loss readings were normalised by initial briquette mass, and a graph of normalised mass was plotted against time. Figure 1 shows a sample curve of a mass/initial mass versus time. There are three phases of the burn marked: Phase (1) is the ignition phase, phase (2) the steady state flaming combustion phase and (3) is when the flame dies and the briquette decomposes further by a char combustion mechanism. The gradient of phase (2) is the normalised steady-state combustion rate, referred to here as the normalised burn rate (NBR). For each briquette burnt,

these graphs were plotted and this quantity was calculated. The next section the results for
NBR are presented for briquettes of different geometries and the trends described.

Figure 6: A typical curve showing the decrease of mass/initial mass of a briquette as a function of time throughout its burn. There are three distinct combustion phases marked and these are described in the text

RESULTS

The effect of density on burn rate

Figure 2 shows curves of how the normalised burn rate of slab briquettes varies as a
function of the briquettes A/V ratio. The curves show that burn rate varies as linear function
of the A/V ratio, with a positive gradient that is greater the lower the briquette density.
Therefore, lower density briquettes have a faster normalised burn rate compared to higher
density briquettes. In practical terms, slabs with a high area to volume ratio will be those that
are either thin or short. In designing a briquette, it is clear from these results that its area to
volume ratio has a very significant effect on the rate. A typical briquette of density 276
161
kgm^{-3}, with a height of 30 mm, an external diameter of 70mm and internal hole diameter of
25 mm would have an A/V ratio of 0.15 mm^{-1} and a mass of 27.8 g, therefore, according to
line (2) in Figure 2, it will have a normalised burn rate of 0.0015 s^{-1} giving a steady state
burn rate for a single briquette of 0.042 gs^{-1}. Changing the height of this briquette to 45mm
would decrease the area/volume ratio to 0.13 mm^{-1}, resulting in a decreasing in burn rate to
0.02 gs^{-1}, a reduction of over 50%. This clearly demonstrates the significance of A/V ratio in
briquette design.

The effect of briquette area to volume ratio on the burn rate for briquettes with slab geometry

Figure 3 shows how normalised burn rate varies as a function of briquette density.
The six curves are for different A/V ratios, the lower one having the lowest at 0.2 mm ±

0.005-1 and the most upper one having an A/V ratio of 0.35 mm ± 0.009-1. There is an exponential decrease in the normalised burn rate with increasing density according to the equation:

(Equation 1)

where =briquette density in and P can be assumed constant and has a value of 0.0023 ± 0.00005.

Figure 7: A graph showing the variation in normalised rate for three different briquette densities

Figure 8: The variation in normalised burn rate of a briquette with briquette density for different area/volume ratios of the briquette. For curve (1) A/V= 0.35 ± 0.009 mm^{-1}, (2) A/V=0.30 ± 0.008 mm^{-1}, (3) A/V=0.27 ± 0.007 mm^{-1}, (4) A/V=0.25 ± 0.007 mm^{-1}, (5) A/V=0.23 ± 0.006 mm^{-1}, (6) A/V=0.2 ± 0.005 mm^{-1}.The dashed curves show that for each data set the points follow an exponential relationship of the form given in equation 1.

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There is a linear relationship between the constant Q for each curve as and the A/V ratio, such that Q =0.074* (A/V)-0.0076. This exponential dependence on density is confirmed by Chin Chin et al. [10] who studied the effect of briquette density on burn rate for a number of different materials. Although their study does not consider newspaper briquettes, the value P found here is of the same order of magnitude as values for other biomass materials, which can be found from simple manipulation of their data. Consequently, for any given A/V ratio, Q can be calculated and with P, now a known constant, the normalised burn rate of a briquette with slab geometry burning in free air can be found according to the equation:

(Equation 2)

This equation demonstrates the significance of a briquettes density and its A/V ratio in determining its burn rate. This equation allows the power output of a briquette to be written as:

(Equation 3)

where is the initial mass of the briquette and is its calorific value. It also allows the steady state burn time of the briquette to be approximately calculated as:

(Equation 4)

where T is the steady state burn time of the briquette. 0.8 appears in the numerator because approximately in each case 80% of the briquette mass is burnt in the steady state phase.

These equations apply specifically to slab-shaped briquettes burning in free air. However, density and the A/V ratio is a physical properties of a briquette, thus these effects will also be very significant in determining the rate in other combustion other conditions. For example this could be in a fixed bed with many briquettes or in briquette stoves. Other conditions have not been investigated as part of this paper, but forms part of the overall research into briquette combustion of which this study is part.

Figure 9: A graph showing the normalised burn rate/exp(-0.0023ρ) for different A/V ratios for cylindrical briquettes, where A/V is varied by changing the briquette height and keeping the other parameters constant. The internal diameter of the briquette= 22.1 ± 0.1 mm and the external diameter is 62.2 ± 0.3 mm. The dashed line give the curve expected for slabs according to equation divided by the factor: exp(-0.0023ρ).

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The burn rate of briquettes with central holes

Figure 4 shows the variation of normalised burn rate/exp(−0.0023) to remove the effect of density) for cylinders with a central hole, where the A/V ratio is varied by changing the cylinder height. The dashed line is for briquettes of slab geometry and it is clear that these results deviate significantly from this line. As the height is increased the A/V ratio of the briquettes decreases. In other words cylindrical briquettes with central holes will have a higher burn rate than slabs of the same A/V ratio. It is important to note that the curve describing this change in rate will never cross the y-axis. This is because as the briquette height increases, the rate of decrease of briquette A/V ratio deceases, until the point where increasing the height further has no effect on A/V ratio. In other words, for a given internal hole diameter and external diameter of a cylindrical briquette there is a maximum height beyond which further increases in the height will not change the effective A/V ratio of a dashed curve describing slab-geometry, giving the cylindrical briquette with a central hole an increasingly higher rate compared to what would have been achieved from the same A/V ratio with slab shaped geometry. The solid black line is a fit of a semi-empirical model that considers the effects of the re-radiation that occurs inside the central hole. This is described in the combustion modelling section. If the briquette height is kept constant and the central hole the same diameter, and the A/V ratio varied by changing the external diameter of the briquette, the resulting curve has the same gradient as that of the slabs, but is shifted to a higher position on the graph. In this case the re-radiative effects and losses inside the central hole are kept constant by maintaining a constant height.

DISCUSSION

Combustion modelling

In this section we offer a quantitative explanation of why the A/V ratio is important, and explain the trend observed for cylindrical briquettes (with central holes) of varying heights (see figure 4). A solid with a large surface area will transfer heat into the mass which it bounds more quickly than if the surface area were small. A large surface area will therefore lead to a more rapidly changing temperature profile passing through the solid mass. Many authors have assumed, with much success, the kinetics of pyrolysis to follow, in a first approximation, a unimolecular law according to the expression (for example [21, 22, 23]):

(Equation 5)

where is the pyrolysis rate constant and is an activation energy, both quantities determined from experiment and assumed constant for a given material.

The greater the rate of heat transfer into the solid, the more rapid the temperature increase of the material, and the more quickly elements of the material reach high enough temperatures for pyrolysis. The result is a greater overall rate of pyrolysis, and therefore an increase in the overall mass burn rate of the solid.

The central hole in the centre of cylindrical briquettes provides an insulated combustion zone resulting in less heat transfer by radiation to the surroundings from this surface. This produces higher temperatures within the hole compared to the outer briquette surface which is in contact with the atmosphere. The steeper temperature gradients result in an increased rate of heat transfer into the solid at this surface, a heat wave moves inside the solid, rapidly increasing its temperature. The result is a faster rate of pyrolysis compared to the outer briquette surface which is exposed to the atmosphere. This increased rate in pyrolysis in the central hole region compared to the outer surface explains the deviation of the burn rate cylindrical briquettes from slabs in figure 4. The deviation becomes greater with increasing height because not all radiation emitted from the surface is reabsorbed within the

hole, a fraction is radiated into the atmosphere and this fraction is a function of the briquette height. The proportion of radiation that is emitted and reabsorbed within the surface of the central hole is known as the view factor and can be calculated by considering how much each unit area of the surface in the hole ’sees’ the other parts of the internal surface. An element towards the top of the briquette will ’see’ a greater portion of atmosphere than an element located in the centre of the hole, and thus the element in the centre will have a greater view factor. As the height increases, the heat lost by radiation from surface elements closer to the top and bottom of the hole becomes a lower proportion of the total central-hole view factor, increasing the overall view factor of the central hole region. As the height tends to infinity, the view factor tends to one and the rate tends to a limiting value determined by the chemical kinetics of combustion. A lower proportion of heat lost to the atmosphere by radiation results in higher temperatures and thus faster a pyrolysis rate.

The solid line is a computational model of this effect which suggests that radiation to the atmosphere is the dominant means by which heat is transferred away from the briquettes surface. These results clearly demonstrate the important role of boundary conditions in determining the briquette burn rate.

CONCLUSIONS AND FURTHER WORK PLANNED

This study has shown the burn rate of biomass briquettes is steady and controllable. Particularly it has been found that the A/V ratio of the briquette, its density and the boundary conditions are all significant in determining the burn rate. An empirical expression for the burn rate of a biomass briquette of slab shaped geometry burning in free air is given. Knowing the normalised burn rate of a particular geometry allows an expression for the briquette power output and the total burn time of the steady state phase to be calculated and equations are given here for slab geometry. Slab briquettes have been compared with cylindrical briquettes with central holes, and it has been shown that the central hole causes this form of briquette to burn faster than slabs with an equivalent A/V ratio. The next stage of this work is the further development of the numerical model and the derivation of a more general expression for briquette burn rate. The study will then look into understanding the burning of briquettes in stoves for cooking and consider the effects of the briquettes physical parameters on harmful emissions. The aim is a more rigorous understanding of the biomass briquette in order that its burn characteristics can be controlled and optimised for a given stove and cooking situation. Ultimately, the results will allow the briquette moulds and hand-presses to be designed to form briquettes with desired burn characteristics.

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COMPARATIVE STUDY ON UTILISATION OF INTERNAL COMBUSTION GENERATOR ENGINES & HYDROPOWER PLANTS IN SOLVING RWANDAN ELECTRICAL ENERGY PROBLEM

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Key words: Hydroelectric energy, thermoelectric energy, cheap electric energy.

Abstract

As energy becomes the current catchphrase in business, industry, and society, energy alternatives are becoming increasingly popular. Hydroelectricity exists as one option to economically, meet the growing demand for energy and is discussed in this paper. Numerous factors exist which must be considered when building hydropower plants; whether the concerns are global or local, each has been measured when discussing this renewable energy source.

The ***internal combustion engine (ICE)*** *is a heat engine in which the burning of a fuel, e.g. gas oil, occurs in a confined space called a combustion chamber. This option of thermally produced electrical energy was adopted by our country Rwanda as a temporary measure to address the immediate energy need and to avoid system collapse. This is because the electric energy produced in Rwanda is practically insufficient. Only a small percentage of naturally endowed energy is tapped. Moreover, Rwanda has significant hydro-electric potential which could constitute a significant source of electric power once entirely exploited.*

Presently ***the cost of kWh*** *of electric energy produced in Rwanda is about* ***0.22USD*** *due to the high cost of gas oil. Thermally produced electrical energy constitutes about 50% of the total electrical energy produced in Rwanda. The objective of this paper is to analyze the problem of electrical energy deficiency in our country, explore and find a more practicable and lasting solution to the problem, minimize cost of maintenance, reduce the amount of thermally produced electrical energy and to provide sufficient and cheap electricity to Rwandan population. In carrying out this research, different modes of data collection and*

methods have been used, such as: interviews, library and web researches, observations and analysis of data.

INTRODUCTION

The electric power energy that our country produces is practically insufficient. Only a small part of naturally endowed energy is tapped. Rwanda has significant hydroelectric potential which could go a long way to solving the energy problem once entirely exploited.

The introduction of generating units known as ICGEs into the Rwandan electric power system made a considerable impact, 50% of the total energy produced in Rwanda. In this comparative study it is clearly shown that the hydroelectric energy is very cheap, clean and renewable compared to the ICGE’s thermoelectric energy.

STATEMENT OF THE PROBLEM

Considering the Rwandan population and the amount of electric energy generated by existing power plants, we can conclude that Rwanda is a country without sufficient electrical energy. The greater percentage of electric energy produced is used in some parts of the country, majorly in urban cities, leaving the greater part of the country without electrical power energy. The growth and expansion of different towns of the country especially Kigali city, the industrial city of the country, and the vision of the government for a sustainable development, have stretched the already insufficient available electrical energy, meaning that the generated energy is no longer sufficient even for the installed load.

As a temporary urgent measure to address this problem, the Rwandan government adopted the option of using Diesel Powered Generator Engines (DPGEs). That implies, an increased consumption of petroleum product (fuel-oil), thus running the station at a very high cost. In fact, DPGEs require large quantities of fuel-oil to keep the station running with the attendant high cost of station maintenance. This results in a very high cost of electricity in our country and constitutes a great obstacle to the investors and the development of the country in general.

HYPOTHESES

- Hydropower energy is the most available, practical and lasting solution to solving the problem of insufficient electric energy production in Rwanda.
- Thermal energy is a temporary solution to solving the problem of insufficient electric energy production in Rwanda, but it is expensive to run and maintain.
- The problem of insufficient production of electric energy can be solved by exploiting all hydropower renewable sources (generated not only within Rwandan territory, but also in partnership with neighboring countries).

COMPARISON BETWEEN GENERATED POWER AND POWER DEMAND

1. Demand in Electrical Energy

According to the data we got from ELECTROGAZ the demand is approximated to be about 60MW considering only the installed areas. This is due to continuous growth and expansion of different towns of the country especially, the industrial town of the country Kigali city, and the vision of the government for a sustainable development.

2. Present Production

In 2005, in addition to the dwindling hydroelectric power generation, ELECTROGAZ with the help of Government rehabilitated Jabana and Gatsata Diesel generators to alleviate the power crisis in the country. This was closely followed by the rental power from Aggreko Gikondo and Mukungwa that have been connected to Rwandan network from November 2005. The actual national produced energy is given in the table 1 below.

Production Unit	**Number of Generator Units**	**Number of Generator Units currently in use**	**Installed Power (MW)**

Current
Production
(MW)
1. HYDROELECTRIC POWER PLANT
Ntaruka 3 1 11.25 1.2 - 3
Mukungwa 2 1 12 3 - 5
Gisenyi 2 2 1.2 0.5 - 1
Gihira 2 1 1.8 1
2. THERMAL POWER PLANT
Gatsata 3 1 4.7 4
Jabana 6 6 7.8 7.6
Gikondo
Rental Power
14 12 10 10
Mukungwa
Rental Power
7 6 5 5
3. IMPORTED POWER 15.5
TOTAL 50.5
Table 1: Actual situation of Energy Production
3. Comparison

When we compare the present demand in electric energy, that is equal to 60MW, and the present production, that is summed up to 50.5MW, we have a deficit in demand which equals 9.5MW. Thus load shedding is unavoidable.

Recall that this concerns only the areas that have electric utility. And we know that there are yet many towns and villages without electricity. [2]

HYDROPOWER PLANNED PROJECTS TO SOLVE THE INSUFFICIENT SUPPLY OF ELECTRICAL ENERGY

The present study confirms that Rwanda is endowed with natural hydroelectric potential. This exploitable potential is found nearly on twenty sites, of different capacities and varies according to selected criteria of classification.

The sites whose realization and exploitation can be carried out independently by Rwanda are those situated inside the country, at various basins of which the widest is Nyabarongo.

The realization of exploitation of other sites will require collaboration with neighboring countries because they are border-rivers. However, there are some constraints in exploiting some of these sites namely:

- Small size of the site.
- Topographical nature of Rwanda preventing accumulation of large quantities of

water.
 Long transmission lines that are required for interconnection to these sites.
 The quality of river water.
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Hydropower Exploitable Sites
i) Internal Exploitable Sites
An evaluation of the most exploitable hydroelectric potential in Rwanda is summarized and
presented in this paragraph. The exploitation of the listed sites is based on technical criteria
and as well as economical. Among the Internal sites that are of much interest include
Rukarara, Mukungwa II and Nyabarongo.
The selection criteria for the above mentioned sites are as follows:
 Rukarara:
- Good quality of water.
- 5 sites in cascade with head comprising between 28 and 40m.
- Its water flow is 5.3m3/s when using only the river and 8.6m3/s when an artificial
reservoir is made.
- Proximity to consumption centers of Gikongoro and Butare.
- Proximity to existing network, facilitating easy connection.
- Total guaranteed producible energy: 64GWh/year.
- Estimated capacity: 11MW.
Presently, this site is under construction.
 Mukungwa II:
- Good quality of water and the head is 40m.
- Flow regulated by Mukungwa I power station is 13.50m3/s.
- Proximity to consumption center of Ruhengeri.
- Proximity to existing network, facilitating easy connection.
- Guaranteed producible energy: 16GWh/year.
- Estimated capacity: 4MW.
 Nyabarongo:
The Government of Rwanda contracted an agreement with two Indian Companies to
execute the construction of Nyabarongo hydropower plant project at the cost of $97.5
million (US Dollars) on Wednesday, July 09, 2008, which when completed, will generate
about 27.5MW.
ii) Frontier Exploitable Sites
The largely untapped hydroelectric potential of River Rusizi and Rusumo falls on the
country's boarders are two examples in this regard.
 Rusizi site

River Rusizi runs about 42km on the border between Rwanda and the DRC (Democratic Republic of Congo). On this section a fall of about 460m is available, with a medium flow rate of about $65 m^3/s$. Indeed the flow is regularized by the Lake Kivu with little or without solid transportation, the slope is significant. Some part of this river has been harnessed namely, Rusizi I and II hydropower plants, but there is a possibility to construct yet another plant (Rusizi III) with a capacity of about 82MW.

- **Rusumo site**

On the Akagera River, the OBK (Organisation du Basin de la Kagera) carried out research on the site of Rusumo, and results showed that an estimated capacity of 61.5MW and annual production of 270GWh is realizable.

The 61.5MW Rusumo falls and 82MW Rusizi III hydropower schemes would be relatively large and would cost approximately $170 million (US Dollars) each. [3]

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ECONOMIC IMPACT OF ICGEs IN RWANDAN ELECTRICAL NETWORK

As it has been stated previously, these ICGEs burn many liters of fuel oil and above this, they are less efficient. And as known, our country is deprived of the fossil reserves, whereas the fuel oil is imported from abroad at a high cost as it is shown in the Table 2 below.

	2005		**2006**	
Power Station	**Consumption in** *l* (liters)	**Fuel cost in USD**	**Consumption in** *l* (liters)	**Fuel cost in USD**
Jabana	6,607,450	5,480,070	5,028,640	4,395,877
Gatsata	4,576,450	3,208,410	338,716	271,051
RP Gikondo	2,798,873	2,231,189	23,612,938	16,233,895
RP Mukungwa	-------	-------	7,310,727	5,124,820
Total	13,982,773	**10,919,669**	36,291,021	**26,025,643**

Table 2: Annual Fuel Consumptions and Costs in 2005 and 2006

In Table 2, we can see that the total annual fuel consumption increased in 2006. And that means more money was spent to keep the ICGEs running. Notice also that in our calculations and data analysis we have not considered the lubricating oil costs and the maintenance costs which are also substantial.

COMPARISON BETWEEN THE USE OF ICGEs AND HPPs IN RWANDAN POWER SYSTEM

From the data we got from ELECTROGAZ and the engineering calculations we made, the production cost for our hydropower plants is ***\$0.01*** $/\ kWh$ **= *5.46RwF*** $/\ kWh$, and the production cost for our diesel power plants is ***\$0.128*** $/\ kWh$ **= *69.904RwF*** $/\ kWh$. From the above results, it is obvious that thermal plants are run at a much higher cost than hydro plants for the same kWh. [2]

ECONOMIC INTERCHANGE OF POWER

Another problem that is encountered by a power system operator has to do with determining when it is economical to buy power from or sell power to other systems.

Whenever power is purchased and received into a system, the power that usually must be produced to carry system load is reduced by the amount of power received from the other system. Conversely, whenever power is sold, power production must equal the system load plus the amount.

When the power output of generating units is increased, the unit incremental cost and also the system incremental cost increase. Conversely, when the power is received from another system, as unit loading is decreased, the system incremental cost also decreases.

When power is sold, the additional incremental production cost must be determined in order to be able to quote a price to the prospective purchaser of the power. When power is purchased, production cost will be reduced and this saving has a value that must be determined. The value of saving in a purchased transaction is called the **decremental value**.

The definitions of these two terms are as follows:

 Incremental cost is the additional cost incurred to generate an added amount of power.

□ Decremental value is the cost saved by not generating an amount of power.
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The seller’ s quoted price (incremental cost) in $ / *kWh* is given by:
▪ ▪ ▪
▪
▪ ▪ ▪
▪
× ▪
▪
▪
▪ ▪
▪ +
=
PenaltyFactor
i OriginalCost NewCost $_t$
1
2 $_{cos}$
The buyer’ s decremental value for the purchaser also in $ / *kWh* is given by:
d OriginalCost NewCost (*PenaltyFactor*) $_t$ × ▪
▪
▪
▪ ▪
▪ +
=
2 $_{cos}$
In purchase and sale transactions, it is customary to split the savings between buying and
selling systems. In other words, the average of the sum of the buyer’ s decremental value and
the seller’ s incremental cost.
( )/ 2 $_{cos\ t\ cos\ t\ cos\ t}$ *Av* = *i* + *d*
The purchasing system would pay the amount equal to the calculated average in $ / *kWh* and
would save the difference between what it would have cost to generate the power and the cost
of the purchased power, that is ( ) $_{t\ t}$ *d Av*$_{cos\ cos}$ − , which represents for example at 1MW
delivery, a **saving of** $(( ) 1000) $_{cos\ cos}$ − × $_{t\ t}$ *d Av* **per hour.** The seller would benefit by the
same amount. [2]

NUMERICAL APPLICATION

From what we got previously, we have seen that the:

· Production cost (Hydro) is of *\$0.01 / kWh*, and the

· Production cost (Thermal) is *\$0.128 / kWh*.

The average production cost for both types of power plants in our country is

$$= \left(\frac{0.01 + 0.128}{2}\right)\$/kWh = \$0.069/kWh$$

Our country also purchases power from neighboring systems such as SNEL (D.R.C.) and SINELAC. The costs of *1kWh* from each plant are given as follows:

· SNEL: *0.043DTS / kWh = 36.543RwF / kWh = \$0.066 / kWh*

· SINELAC: *0.055DTS / kWh = 46.741RwF / kWh = \$0.085 / kWh*

DTS (Droit de Tirage Special) is the type of currency and according to the rate of exchange from the National Bank of Rwanda, 1DTS = 849.839RwF and \$1USD = 546.761RwF.

The average cost of the purchased power is

$$= \left(\frac{0.066 + 0.085}{2}\right)\$/kWh = \$0.075/kWh$$

Let's now suppose that *\$0.069 / kWh* is the original cost of the power produced in our country and *\$0.075 / kWh* is the new cost of the power purchased from neighboring systems.

From the data we collected from ELECTROGAZ, the transmission losses during that period are 22% equivalent to a loss factor of 0.22. Thus, the penalty factor is given by

$$\frac{1}{1 - L} = \frac{1}{1 - 0.22} =$$

$LossFactor$

$L = 1.28$

Having calculated the above results, we can now find the incremental cost and the decremental cost as follows:

$$\cos t_i = \frac{1}{1.28}\times\left(\frac{0.069+0.075}{2}\right) = \$0.056 / kWh$$

$$\cos t_d = (1.28)\times\left(\frac{0.069+0.075}{2}\right) = \$0.092 / kWh$$

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The average of the sum of the buyer' s decremental value and the seller' s incremental cost is:

$$\cos t_{Av} = \left(\frac{0.056+0.092}{2}\right) = \$0.074 / kWh$$

Our country would pay the amount of *$0.074 / kWh* and would save, for example at 1MW delivery,

$\$((0.092 - 0.074) \times 1000)/h = \mathbf{\$18}/h$

The seller would benefit by the same amount. [2]

ADVANTAGES OF HPPs OVER ICGEs IN RWANDAN POWER SYSTEM

HPPs(Hydropower Plants) ICGE(Internal Combustion Generator Engines)

 Clean, renewable and reliable energy source.
 Cheap electricity.
 It has operational flexibility.
 Low running cost.
 Low maintenance cost.
 High efficiency.
 No waste products.
 Since Rwanda is endowed with hydroelectric potentials, the use of HPPs is practical and the right choice.
 Not renewable energy source, it pollutes the atmosphere.
 High energy tariff.
 Standby reserve.
 High running cost.
 High maintenance cost.
 High consumption of petroleum products.
 Much noise and pollutants.
 The use of ICGEs in our country is an immediate solution but not a lasting one.

CONCLUSION

Generation and the supply of electricity under various economic, environmental, social and political constraints is one of the major challenges in this 21st century. The best energy is the cheapest [Prof. Rubbia, Nobel Price, physics].

In our study, we compared the utilization of Internal Combustion Generator Engines and Hydropower Plants in solving Rwandan problem of insufficient electric power supply and analyzed data collected from different sources (e.g. ELECTROGAZ, Aggreko and MININFRA). From this study we have been able to prove that hydropower energy is the most available, practical and lasting solution to solving the problem of insufficient electrical energy production in Rwanda. Notice that the cost of 1kWh of electric energy produced in

Rwanda is too expensive, about the highest in Africa due to the introduction of the ICGEs,
which consume large quantities of petroleum products.
We hope that by the time the vision 2020 brings all the exploitable sites into operation
the cost of 1kWh of electric energy in Rwanda will become the cheapest within the East
African Community.

RECOMMENDATIONS

We make the following recommendations:

 To the Rwandan Government

- The Government should restructure ELECTROGAZ with the aim to increase private sector participation and improve managerial and operational performance.
- The Government should expedite action on the ongoing methane project and boost power electric energy production since about 82% of Rwandan population lives in rural areas and the majority of them don't have access to electricity.

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- Regional cooperation between Rwanda and her neighbors can solve some energy problems.

 Lastly, to the electricity consumers we recommend that bills be paid promptly and illegal
connections be discouraged.

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Breeding a Better Stove: the Use of Genetic Algorithms and Computational Fluid Dynamics to Improve Stove Design

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combustion, stoves, wood, genetic algorithms, computational fluid dynamics.

Abstract

Half the world cooks using wood, often on open fires or on inefficient stoves. Collecting firewood is often left to women and children. As well as reducing the time available for education and other activities, there are many cases of women being raped while trying to collect firewood outside of refugee camps in the Darfur region. The aim of this research is to produce optimised wood stoves, reducing the amount of wood required, hence reducing carbon emissions, and improving the quality of life, particularly for women and children.

Our approach is to use computational fluid dynamics and genetic algorithms to improve the combustion conditions in wood-burning cook-stoves. In the initial experimental phase, open wood fires were characterised in terms of burn-rate, and gas temperature and velocity. Several stove designs were also assessed, including the three-stone fire (3-5% efficient), the Eritrean mogogo (5-10% efficient) and the rocket elbow (20-30% efficient).

The experimental results were replicated in a computer simulation which was validated for a range of fires. This model was embedded in a CFD package which correctly predicted the flame height, velocity and temperature.

The validated CFD model combined with a genetic algorithm was used to optimise stove design: each stove is defined by a genome describing its dimensions; the various designs are allowed to "mate", each one vying for the attention of the "fittest" or most efficient stove; the offspring inherit a mixture of their parents' features, until an optimum design emerges. Finally the optimised design is to be built and physically tested before being modified to make it suitable for field trials and dissemination to rural communities.

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Introduction

Half the world cooks using wood, often on open fires or on inefficient stoves. Collecting firewood is often left to women and children. As well as reducing the time available for education and other activities, there are many cases of women being raped while trying to collect firewood outside of refugee camps in the Darfur region**.

There have been many attempts to produce fuel-efficient stoves or to replace wood stoves with other fuel sources or alternative means of cooking. Often research is carried out in academic institutions away from where stoves are used and although the resulting stoves can be fuel efficient, the neglect of social factors is a major barrier to successfully introducing improved stoves into the homes of those living in remote communities. In Ethiopia and neighbouring Eritrea, the staple food is injera: a spongy sour delicious flatbread, is cooked on a large griddle on a mogogo stove (see Figure 1). These inefficient, smoky stoves are made by individuals from a mixture of mud and clay, whilst the mogogo plates are supplied by the local ceramics industry. Two recently proposed "improved" stoves are not suitable for cooking injera (see Figure 1). The CleanCook alcohol stove [1], made in Sweden from aluminium, has two small burners which are insufficient to heat a mogogo plate. The change of fuel and stove also has adverse economic effects on local mogogo plate manufacturers and firewood sellers. A stove from Aprovecho with a more traditional appearance but made from concrete failed to take into account the even temperature distribution required, so although testing in the USA by boiling pots of water appeared to show improved efficiency, when it came to cooking injira, the results were inedible. Although these laudable attempts have some merit, their use requires Ethiopians to change their eating habits, threatens local economies and could thus be regarded as intrusive and colonialistic.

Figure 1: top left: classic mogogo, top right: Aprovecho improved mogogo, bottom left: ERTC design, bottom right: Cleancook stove.

** See: www.darfurstoves.org

There is also a design of mogogo promoted by the Eritrean government - the ETRC (Energy Research and Training Centre) mogogo, but the cost of US $40 places it out of reach of many Eritreans.

Alternative approaches involving local stakeholders have tended to be successful on a small scale, but are much more labour intensive. For example, on a recent trip with Engineers Without Borders UK in conjunction with FAMUSOD to install wood stoves in a remote village in the Imbabura region of Ecuador, Nottingham University student Rob Quail found that although initially the villagers were rather shy, by involving them in the design and material selection process, they overcame scepticism. After taking a break to go trekking for two weeks, Rob returned to the village to find that the villagers had built two stoves from his design and had begun to experiment with modifying the stoves according to their own ideas [2].

It may be impractical to involve end-users at every stage of the process in the design of improved cook stoves. An alternative approach is to tackle the problems of poor fuel economy and harmful emissions by modifying stoves which are currently in use rather than starting with a blank sheet of paper. Indigenous stoves will have undergone a natural process of evolution, with good stoves being imitated and bad ones replaced, although we must exercise caution in defining the characteristics of good stoves. A project to replace smoky stoves in Nepal was successful in eliminating harmful indoor air pollution, but after six months, several dwellings collapsed due to termite damage; the previously used smoky stoves had been effect at killing pests whereas the new improved stoves did not fulfil this secondary (but essential) function [3].

A good example of using local knowledge in stove design is the Mirt stove distributed in Ethiopia by GTZ (see Figure 2). The stoves are made of concrete from simple moulds provided to local artisans. They are suitable for cooking injera and are fitted with traditional mogogo plates, protecting another sector of the local economy. However, these stoves are not suitable for use in Eritrea, due to the on-going tension between the neighbouring countries.

Eritreans are likely to be suspicious of technology developed in Ethiopia - another factor traditionally ignored by engineers designing stoves.

Figure 2: Mirt stove

Whilst the evolutionary approach to stove design is commendable for the way in which it builds up local communities, supports the local economy and fosters a sense of ownership, the process is frustratingly slow and costly in terms of the number of new stoves that have to

be built and tested, many of which will not show any improvement on the previous generation. A novel approach is to make use of genetic algorithms and computer modelling. Traditional stoves are allowed to "mate" with stoves with good fuel efficiency, such as the rocket stove depicted in Figure 3. The offspring stoves are modelled using Computational Fluid Dynamics (CFD) and assessed in terms of fitness. Fitness can be defined to include factors such as: fuel efficiency, temperature distribution, volume of material used to construct the stove (indicative of cost) and so on. In this paper we apply the methodology to the Eritrean mogogo. Details of the computational modelling and genetic algorithm (GA) are given in the next two sections, results of the simulations are then presented and discussed before conclusions and considerations for future work are proposed.

Computational Modelling

The computational fluid dynamic model of stoves was developed in Fluent 6.2, with a bespoke user-defined function to describe the rate of fuel combustion in the fuel bed. The model was simplified by assuming steady state conditions and an axi-symmetric domain, divided into three regions: the solid parts of the stove; a porous fluid region to describe the fuel bed and; a non-porous fluid region to describe the rest of the gases in the stove. The standard axi-symmetric Navier-Stokes equations were solved, coupled with the energy equation, the $k-\varepsilon$ model with enhanced wall functions to describe turbulence, the discrete ordinates model to describe radiation heat transfer and the species transport model to describe chemistry with homogenous reactions limits by turbulent mixing as per the eddy dissipation model. No soot model was included, and it will be shown that neglecting the effect of soot on flame radiation has resulted in some significant errors.

Behaviour of solid fuel in the stove was described by a fuel sub-model, written as bespoke Ccode and attached to Fluent as a user-defined function. The sub-model avoided the requirement to model each piece of fuel separately, instead applying a non-uniform flow resistance coefficient to the fuel bed, calculated from the Ergun equation. The model only accounted for the active (burning) surfaces of the fuel which were grouped together in lumps throughout the fuel bed: this was necessary in order to make combustion in the resulting flame diffusion limited as volatile matter and oxygen mix, rather than kinetically limited.

Within each lump, the rate of volatile release was limited by the transfer of heat through a char layer of assumed thickness to the virgin fuel below. The rate of char combustion was limited by the supply of oxygen from free stream conditions through the species boundary layer to the char surface. The approach is novel, but the numerical model of buoyancy-driven flow was validated against experimental data from the literature [4]; the fuel model was validated against experimental data [5] and convection heat transfer as the plume of hot gases impinge on the cooking surface was also validated against experimental data [6]. Mesh independence of the model was assessed using the Richardson extrapolation.

Figure 3: Principal rocket stove dimensions. Variable dimensions are denoted A to F. T1..7 indicates location of thermocouples for experimental testing.

Genetic Algorithm

The genetic algorithm (GA) mimicked Darwinian evolution following the pseudo-code in

Figure 4. A generic stove was developed from the Rocket stove [7,8] which had previously been assessed experimentally. This stove was almost axi-symmetric, with an annular air inlet between the stove and the ground, a window to allow fuel to be introduced and a mogogo plate (or similar) atop as a cooking surface. For each stove a gene of single-digits scalars was stored. These were multiplied by a generic set of vectors to yield a unique stove shape for each gene or creature. The GA is an iterative process, and for each stove in each generation, the dimensions of the stove were derived as described above. The GA inserted the new dimensions into a journal file which was executed in the meshing software, Gambit 2.1, to give a coherent mesh. The mesh was then sent to Fluent 6.2 where a second journal file imposed boundary conditions, models and model parameters and set the simulation to solve for 2000 iterations. At the end of the calculation the GA exported data on the fuel burn rate and the local heat flux to the cooking surface. Finally the fitness of each stove in the generation was calculated according to the following objective function:

$$f = g(q'') + h(q'')\, m'^{2}_{f} \quad (1)$$

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where q” is the mean heat flux passing through the cooking surface and m'_f is the total fuel burn rate. Functions g(q”) and h(q”) are described in Figure 5. The objective function primarily rewards stoves which achieve the target heat flux (q''_t) using the first term in Equation 1, and only when that is achieved does it heap additional fitness on stoves that minimise their fuel consumption, using the second term in Equation 1. Earlier embodiments of the objective function had an additional term to reward a uniform heat flux by monitoring local deviation from the mean flux, but this was found not to be necessary.

Figure 5: Functions $g(q'')$ and $h(q'')$, which contribute to the overall objective function.

Once the fitness of all stoves had been assessed, the GA moved on to the mating phase, using the roulette wheel selection routine: a virtual roulette wheel was created with sectors sized in

```
initialise random genome of creatures
FOR each generation
FOR each creature
transform gene into mesh
call CFD to calculate fluid flow
calculate fitness from CFD results
ENDFOR creature
select mates
cross-over to create new generation
mutation on new generation
new generation usurps old generation
ENDFOR generation
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Figure 4: Pseudo-code of Genetic Algorithm.

proportion to the fitness of each stove. Two roulette balls were set into the wheel to identify two parents. The genetic code of the two parents was mixed using a single cross-over point to produce a child. The child's genetic code was then subject to random mutations. The fittest stove from the previous generation passed automatically to the next, and the rest of the population was generated by random mating events: this encouraged rapid convergence of the results to an optimum stove design. Finally the new generation of stoves usurped the old.

The GA was run with $q''_t = 5000$ W/m^2, giving 1 kW cooking power over a 0.5m mogogo plate. There were 10 stoves in a population and the GA was run for 50 generations. The GA was run for 10 heats, generating ten champions from random initial genomes. In a second phase, the ten champions were set against each other three separate times to give a champion of champions. The champion of champions (i.e. the best stove) was subject to a sensitivity analysis, whereby all dimensions were subject to small perturbations and the effect on stove performance was assessed to identify critical dimensions.

Results

The champion of champions is illustrated in Figure 6. It features a sharp "turbulator" (at height, z=0.32) and a recirculation region in the combustion chamber, a wide thin virgin fuel region and a tall lower section. Errors in heat flux and fuel burn rate for the optimum stove were estimated to be 2% and 40% respectively using the Richardson extrapolation: results concerning the fuel burn rate should be treated with circumspection.

The turbulator and thin neck (z = 0.34 m) supports a large block of material. It is anticipated that these two features could easily break and render the stove useless, so a further sensitivity analysis was conducted on this region of the stove. Reducing the turbulator size reduces fitness from 6470 to 4220. Removing the turbulator completely results in a further decease to 3980. Clearly the large turbulator is important for mixing and heat transfer: a smaller version is almost as useless as no turbulator at all, and a final design would have to include an insert in this region to (a) act as the turbulator and (b) strengthen the neck. This is unfortunate as it would increase the price of the resulting stove, and move away from the initial design philosophy that the optimised stove could be manufactured on an ad hoc basis by rural women without specialist training nor recourse to purchasing components.

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Figure 6: Schematic of the best stove proposed by the GA. The dashed line shows an improvement identified by the sensitivity analysis. The x-axis is the rotation of symmetry, the y-axis is the ground and solid material is shown shaded.

Conclusions

The proposed stove achieved a target cooking heat rate of 997W, using fuel at a rate of 0.6 g/s. This performance is equivalent to 12% efficiency or specific fuel consumption 0.4 kg fuel per kg food, compared to 0.5 for the classic mogogo. This result has not been experimentally verified, and should be viewed with circumspection given the shortcomings of the CFD model. Nonetheless, the proposed stove requires only one bought component, the turbulator, with an estimated cost US$ 1, which compares favourably to the cost of the optimised ERTC mogogo (US$ 40) and the Aprovecho design (US$ 9) and in that respect it has realised the requirements of the project. Considerable further work is required in experimental verification, to adapt the design to manufacturing requirements and to successfully bring it to market in Eritrea.

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Who Will Be the Players in Green Technology and What Will Their Role Be?

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Abstract

At long last the general public and businesses have gotten the message. Something must be done about the rising cost of imported oil, and high carbon emissions from it and other fossil fuels that lead to global warming. One solution is to reduce the emissions and energy costs and develop of alternative energy or renewable energy sources/green technologies. The development of alternative energy sources or "green technology" once the focus of small businesses, is now on the radar screen of major corporations. The shift to various alternative energy sources has produced some interesting dynamics. Development of Green Technology is equated with the expansion of the economy and job market. The development of alternative energy sources has become big business funded by corporate giants in the oil and semiconductors industries. Solar energy companies are now traded publicly on the stock market. The alternative energy sources introduce new players to the energy business, but the financiers are players with the gold and they rule. Farmers, semiconductor technologists and energy innovator , biologists, venture capitalists, politicians, architects, city governments, new energy providers such as integrate solar companies. Community based and development organizations and individual energy producers are among the new players who receive modest benefits. This paper will explore who will play a role in Green Technology, and the dynamics that influence what their role will be. Examples of development of solar and biomass will be provided.

INTRODUCTION

Recent National Oceanic and Atmospheric Administration (NOAA) studies are pretty convincing that the carbon emissions from energy production and use is leading to global warming [1]. One of the solutions to this problem is to replace the existing energy sources with alternative energy or renewable sources that are cleaner. However, with energy as the

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driving force behind the US economy, shifting to alternative energy sources can have major implications and potential impact on maintaining the status quo of the economy. Energy is big business, and all indications are that it will stay big business even with renewables.

Ninety per cent of renewables are used to produce electricity; therefore, examples of the application of renewables to generate electricity will be focused upon in this paper. The direction of renewable energy development will be covered and the players that make it happen will be described.

Current Status of Renewable Energy

For a century, energy supply, use and demand have been controlled and manipulated by petroleum based(oil) companies that have annual profits that exceed most global economies. Traditionally, electrical generation for commercial industries and residences has been run by large centralized public utilities. Renewable energy is 7% of the energy supply and 90% is tied to the electric grid (in the USA).

The Role of Renewable in Energy Consumption in the Nation's Energy Supply, 2006

Figure 1. The Role of Renewable Energy Consumption in the Nation's Energy Supply, 2006 [2]. Biomass is the largest source of renewable energy

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Figure 2. To reach parity **Figure 3.** PV market Distribution]
Solar must cost less than 10cents
per kwh [3]

Germany's PV market reached 1,328 MW in 2007 and now accounts for 47% of the world market. Spain soared by over 480% to 640 MW, while the United States increased by 57% to 220 MW. It became the world's fourth largest market behind Japan, once the world leader, which declined 23% to 230 MW. World solar cell production reached a consolidated figure of 3,436 MW in 2007.

Discussion-Players in Solar and Biomass Energy and Their Roles

Solar Energy

To accelerate the pace of the shift to alternative energies, some state governments are now mandating milestones for public utilities to increase the per cent of electricity produced from renewable energy. California is attempting to pass an initiative, Proposition 7 that requires utilities to produce 20% of their power with renewable energy by 2010, 40% by 2020 and 50% by 2025 [5]. Some cities such as San Francisco are proposing to manage and produce their own electricity. The goal is to shift the electrical production to 100% renewable energy. In each case, the focus is centralization of control of the production of renewable energy. This initiative is modelled after the German approach to solar.
The centralized approach leads to utility scale renewable projects in the 400-600 megawatt range that can only be managed and constructed by capital rich corporations.
Utility-scale PV solar projects feature photovoltaic solar modules, which convert sunlight directly into electricity and produce the greatest amounts of power during the afternoons, when electricity demand is high.
For example, PG&E, a California public utility, entered into an agreement with Topaz Solar Farms LLC, a subsidiary of OptiSolar Inc., for a 550 MW of thin-film PV solar power plant and with SunPower for a 250 MW solar power plant. Both plants would be located in San Luis Obispo County, California (100 miles north of Los Angeles). The SunPower plant will deliver an average of 550,000 megawatt-hours of clean electricity annually. The project is expected to begin power delivery in 2010 and be fully operational in 2012. The OptiSolar project would deliver approximately 1,100,000 megawatt-hours annually of renewable electricity and is expected to begin power delivery in 2011 and be fully operational by 2013.

It will cover 10 square miles. Combined the two project will produce electricity for the energy needs of 239,000 residents. Both projects are contingent upon the extension of the federal investment tax credit for renewable energy and processes to expedite transmission needs [6].

Over the past six years, PG&E has entered into contracts for more than 3,600 MW of renewable power, including solar contracts that total more than 2,500 MW. PG&E now has contractual commitments for more than 24 percent of its future power deliveries from renewables, including wind, biomass and geothermal [7].

Such projects are ideal for the subsidiaries of oil giants. OptiSolar is backed by private equity firms apparently with oil connections [8]. SunPower is backed by Cypress Seminconductor Corporation which owns 52% of the company [9],

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It is deals like this that makes renewable energy attractive to other oil giants like BP, Chevron and Shell and semiconductor companies like Sharp Electronics and Siemens. These are the players that are accelerating the alternative energy market and creating publicly traded renewable energy companies that began to appear in 2004 on the U.S. stock market. They have the gold and continue to rule.

Building solar power plants for utilities and franchised businesses will probably squeeze out the smaller under-capitalized renewable energy companies who are ill equipped to bid on such large scale projects. They probably will be limited to small commercial and residential projects which will dry up as the utilities take over solar energy production. They must also share their profits with suppliers and the customers to make solar affordable on the smaller scale. With utilities as the producers of solar electricity, the need to continue government rebates and tax incentives for the small energy users is significantly reduced.

Environmentalists and small solar energy companies are opposed to Proposition 7 because the initiative was written without input from renewable experts and proposed by a billionaire from another state who is not an expert [10]. Setting milestones for the utilities to become renewable energy producers without adequate studies of impact could result in large scale projects that have adverse and unknown impacts on the environment and economy.

Scaling up project sizes that only major corporations can handle marginalizes the participation of small companies and shifts the current market away from the decentralization that provides individual control of energy production. The oil companies have been preparing for the alternative energy shift for more than three decades, evidenced by their investment in biofuels and the establishment of subsidiaries such as BP Solar in the 1970’s. BP Solar is one of the largest solar companies in the world.

For decades, the solar energy industry was carried by small businesses with less than 20 employees because it was not very profitable, and the market focus was on small commercial and residential projects. Home installations averaged 3kw of solar power and large commercial installation were only double digit figures. A 3 kW solar power generation system of the type designed for general home use can produce approximately 3,000 kWh of electricity over the course of a year. The effect of this is equivalent to a 540 kg-C equivalent reduction in carbon emissions annually.

The solar market was supported partially by government subsidy programs and tax credits. Most solar systems installed privately were tied to the electrical grid. The solar producer’s meters runs backward to credit production. At the end of the year, usage and production are reconciled. No compensation is given for access to electricity produced because of the government subsidies and tax credits given upfront.

Participation in the subsidy programs was on a volunteer basis, and was designed to help expand the solar industry to reduce the cost of solar photovoltaic cells. At the end of

2007, according to preliminary data, cumulative global production was 2,400 megawatts (mw), less than 1% of the global need. It resulted in a small reduction of the amount of electricity that utilities need to produce from conventional sources. Rebates, and tax incentives did not lower costs and the industry grew very slowly. For example, the 120W Kyocera solar cell purchased in 2002 at $ 499 or $ 4.15/w are now $ 614 or $4.99/w (20 per cent more).

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Large investments into the industry are making a difference and have created a viable market. Now that it is real, everyone what to be a player. The U.S. Presidential candidates talked about green-collar movements and pledged the creation of millions of new jobs, job training for current and future workers, and the identification of green industries of the future.

Community based and development organizations are clamoring for green jobs and a piece of the pie albeit it the crumbs.

Republican Sen. John McCain -- "We have the opportunity to apply America's technological supremacy to capture the export markets for advanced energy technologies, reaping the capital investment and good jobs it will provide."

Democratic Sen. Barack Obama -- "We've also got to do more to create the green jobs that are jobs of the future. My energy plan will put $150 billion over 10 years into establishing a green energy sector that will create up to 5 million new jobs over the next two decades."

The green that matter is money by the billions wrote Fortune Magazine's Marc Gunther. Fortune 500 companies, including BP Solar, SunPower, General Electric, Mitsubishi, Sanyo, Sharp, and Shell, all want to grow their solar businesses.

In Silicon Valley, meanwhile, venture capitalists like John Doerr and Vinod Khosla, entrepreneur Bill Gross, and Google founders Larry Page and Sergey Brin are backing startups that claim they will revolutionize the industry. Chevron Technology Ventures LLC, a subsidiary of Chevron Corporation, identifies, develops and commercializes emerging technologies and new energy systems including hydrogen-related technologies, advanced energy storage technologies, renewable energy and nanotechnology. Chevron, formerly primarily petroleum-based, has expanded into a number of renewable energy technologies.

Solar energy development is definitely a hot item in the stock market. According to John Cavalier, who is chairman of the energy group at Credit Suisse, the market value of the world's publicly traded solar companies stood at about $1 billion in 2004. Now, after a slew of Initial Pubic Offerings (IPOs), they are worth about $71 billion. If the U.S. enacts legislation to counter global warming and it adds to the cost of making electricity from coal, natural gas, and oil, solar energy will be among the winners. "The opportunity for solar companies is absolutely tremendous," Cavalier says.

Major photovoltaics companies include BP Solar, Isofoton, Kyocera, Q-Cells, Sanyo, Sharp Solar, SolarWorld, SunPower, Suntech, and Yingli Green Energy representing the U.S.,Spain, Japan, German, and China. The best-positioned companies are integrated solar players (REC, SolarWorld, SunPower, Suntech representing Norway, Germany, U.S. and China). Integrated companies are those that desgn, manufacture, construct and install utility scale solar systems. In addition, downstream companies with the skills necessary to originate power deals in multiple markets have very strong growth potential (e.g. Conergy and SunEdison)[88] .

Table 1. Top 20 Global Solar Companies and Energy Capacity from 2007-2010. [11]

Sharp Solar Energy Solutions Group, a group of Sharp Electronics Corporation is the world's oldest and largest (disputed by Q-cells) photovoltaic module and cell manufacturer, produces solar panels in Japan, and near Wrexham, UK. It has been producing solar energy for a half century. SunPower was considered a dead business until Cypress Seminconductor financed it in 2005. The company owns 52% of the business.

Biomass

Biomass is agricultural product specifically grown for conversion to biofuels. These include corn and soybeans. R&D is currently being conducted to improve the conversion of non-grain crops, such as switchgrass and a variety of woody crops, to biofuels. The energy in biomass can be accessed by turning the raw materials of the feedstock, such as starch and cellulose, into a usable form. Transportation fuels are made from biomass through biochemical or thermochemical processes. Known as biofuels, these include ethanol, methanol, biodiesel, biocrude, and methane. Agriculture and forestry residues, and in particular residues from paper mills, are the most common biomass resources used for generating electricity and power, including industrial process heat and steam, as well as for a variety of biobased products. Use of liquid transportation fuels such as ethanol and biodiesel, however, currently derived primarily from agricultural crops, is increasing dramatically [12].

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Currently, a majority of ethanol in the U.S. is made from corn, while Brazil uses primarily sugar cane. New technologies are being developed to make ethanol from other agricultural and forestry resources such as:

- corn stover (stalks and residues left over after harvest);
- grain straw;
- switchgrass;
- quick growing tree varieties, such as poplar or willow; and
- municipal wastes.

The Department of Energy makes funding for research and development related to biofuels available via competitive solicitations. In 2007, BP, now referred to as a Global Energy Company also present in the solar industry, selected UC Berkeley to lead the $500 million energy research consortium with partners Lawrence Berkeley National Lab, and

University of Illinois.The funding will create the Energy Biosciences Institute (EBI), which initially will focus its research on biotechnology to produce biofuels – that is, turning plants and plant materials, including corn, field waste, switchgrass and algae, into transportation fuels [13]. BP adopted a new slogan in 2000, "Beyond Petroleum" and changed its logo to rebrand itself as a green company.

Biofuels have been commercially successful in several countries. Brazil (ethanol) and Germany (biodiesel) are two examples. In Brazil, "Eighty percent of the 2005 production (ethanol) is anticipated to meet national demands (transportation fuels). In Germany, the last ten years consumption and production of biodiesel has increased several fold. In 2004, 1.18 million tones were produced, up 45 percent from 2003 and an additional 500,000 tonnes were planned for 2005 [14].

Key biomass energy players are already present in the Netherlands and include Biopetrol, which is building a biodiesel plant at Vopak's terminal, and WHEB Biofuels and Argos Oil, which are also building biodiesel plants there.

Conclusion:

Renewable energy is no longer unprofitable and small business. Companies are publicly traded and worth over $71 Billion. The infusion of hundreds of millions of dollars in renewable energy startups by capital rich petroleum-based and semiconductor -based companies behind the scenes has made the renewable energy industry big business and led to real growth. Government incentives have been critical to make these investments. There are some new faces in energy renewables that have become IPOS, but they are financially backed and often controlled by parent corporations entrenched in conventional energy sources. New comers like farmers, small businesses, and job seekers will benefit modestly from the renewable energy boom. The technical innovators fair a little better, but he who has the gold rules.

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