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Biogas Production from Water Hyacinth Case of Lake Chivero - Zimbabwe A review

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Abstract-The purpose of this study was to review the energy situation in Zimbabwe as well as the possibility of producing biogas from water hyacinth. Zimbabwe faces a shortage of electrical energy owing to internal generation shortfalls and the country imports all its petroleum fuels at a huge cost.The majority of people in Zimbabwe as a developing country are dependent on traditional and inefficient energy services that constrain their ability to enhance economic productivity and quality of life. The water hyacinth weed has invaded approximately all rivers, lakes and dams in Zimbabwe and government authorities are relying on research institutions to come up with solutions to deal with this invasive weed. The costs connected with elimination and maintenance control of water hyacinth are quite considerable. This study found out that the option of biogas production as a way of energy exploration using water hyacinth may not only sustain the energy availability but also improve environmental sustainability by improving the social, economic and physical well being of the environment.

Index Terms – Biogas, Lake Chivero, Renewable energy, Water Hyacinth

I. INTRODUCTION

Energy consumption has increased steadily over the last century as the world population has grown and more countries have become industrialized. Biogas, a renewable biofuel is becoming increasingly important as a consequence of major concern for depleting oil reserves, rising crude oil prices and greenhouse effect. Lignocellulosic feedstock is considered as an attractive raw material because of its availability in large quantities at low cost (Parisi, 1989) not only for the liquid transportation fuel but also for the production of chemicals and materials, i.e. the development of carbohydrate-based biorefineries (Farrell et al., 2006). Besides terrestrial plants, aquatic plants are also a promising renewable energy resource. Water hyacinth, Eichhornia crassipes is such an aquatic plant.

Water Hyacinth (Eichhornia crassipes Martius) is a monocotyledonous freshwater aquatic plant, belonging to the family Pontederiaceae, related to the lily family (Liliaceae) and is a native of Brazil and Equador region. It is also a well known ornamental plant found in water gardens and aquariums, bears beautiful blue to lilac colored flowers along with their round to oblong curved leaves and waxy coated petioles. It grows from a few inches to about a meter in height. The stem and leaves contain air filled sacs, which help them to stay afloat in water. Water hyacinth is considered as a noxious weed in many parts of the world as it grows very fast and depletes nutrient and oxygen rapidly from water bodies, adversely affecting flora and fauna. There have been instances of complete blockage of waterways by water hyacinth making fishing and recreation very difficult. Shoeb and Singh (2002) reported that under favorable conditions water hyacinth can achieve a growth rate of 17.5 metric tons per hectare per day. There is a great discrepancy among policy makers, environmental agencies and research scientists on the way to control this invasive species and the practical benefits that can be obtained (Lu et al. 2008). There is a need for sustainability and a new perspective when it comes to managing this species, understanding and implementing their marketability as a newly found biofuel crop. Biomass may sometimes be a source of environmental nuisance, for example water hyacinth has been implicated in affecting navigation and fishing activities in water ways (Gopal, 1987). Also municipal solid waste and cow dung have been implicated in poor aesthetic quality of environment and pollution of surface and ground water sources. Thus, the option of energy exploration using biomass may not only sustain the energy availability but also improve environmental sustainability by improving the social, economical and physical well being of the environment.

II. ENERGY AND DEVELOPMENT

Jigar 2010, highlights that energy is essential to economic and social activities and therefore every person has access to energy services of one kind or another. The International Atomic Energy Agency agrees that energy is central to improved social and economic well-being, and is indispensable to most industrial and commercial wealth generation and that it is key for relieving poverty, improving human welfare and raising living standards (IAEA, 2005). Energy today is at the heart of every economic, environmental and developmental issue. The world requires clean, efficient and dependable energy services to meet up its long-term needs for economic growth and development.

Developing countries need to expand access to reliable and modern energy services to alleviate poverty and increase productivity, to enhance competitiveness and economic growth. (UNIDO, 2008). According to the Zimbabwean National Energy Policy (2012), there is a direct correlation between the level of a country's development and the quality and quantity of its energy services. The majority of people in Zimbabwe as a developing country are dependent on traditional and inefficient energy services that constrain their ability to enhance economic productivity and quality of life. (MoEPD, 2009).

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III. ENERGY SITUATION IN ZIMBABWE

The main sources of energy used in Zimbabwe comprise of coal, wood fuel and petroleum fuels. According to the national energy balance of 2009, wood fuel provides the bulk (61%) of the total energy supply, followed by liquid fuels (18%), electricity (13%), and coal (8%). (NEP 2012). 37% of households in Zimbabwe have access to electricity that is connected via power lines. There is a significant difference between urban and rural areas in their access to electricity. In urban areas 83% of households have electricity, compared with 13% in rural areas. (NEP 2012)

Rural communities Zimbabwe meet 94% of their cooking energy requirements from traditional fuels, mainly firewood, and 20% of urban households use wood as the main cooking fuel. Coal, charcoal and liquefied petroleum gas (LPG) are used by very few households (less than 1%). A majority of urban households use electricity for cooking (73%); in contrast, only 6% of rural households use electricity for this purpose (NEP 2012). Most of the rural areas of Zimbabwe are facing a wood fuel shortage owing to; inter alia, the clearing of land for agriculture and unsustainable firewood harvesting. Zimbabwe faces a shortage of electrical energy owing to internal generation shortfalls and the country imports all its petroleum fuels at a huge cost.

IV. WATER HYACINTH (EICHORNIA CRASSIPES)

Water hyacinth (Eichhornia crassipes) is originally from South America and is one of the world's most widespread invasive aquatic plants. This vascular floating plant is known to cause major ecological and socio-economic alterations (Center, 1994). It normally forms thick, intertwining mats due to its fast reproductive rate and intricate root structure (Mitchell, 1976). Water hyacinth is indigenous to the Amazon Basin of Brazil but has been introduced to tropical and subtropical regions around the globe (Langeland and Burks 1998). Holm et al. (1977) noted that by 1977, 56 countries including the United States had reported water hyacinth as a noxious weed.

Bartodziej & Weymouth agreed with Holm and others that water hyacinth has invaded freshwater systems in over 50 countries on five continents and that it is especially pervasive throughout Southeast Asia, the southeastern United States, central and western Africa, and Central America (Bartodziej & Weymouth, 1995; Brendonck et al., 2003). It is widespread in tropical and subtropical water bodies where nutrient levels are usually high owing to deforestation, agricultural runoff, and inadequate wastewater treatment.

Jigisha et al., 2004 reports the water hyacinth to have a measured HHV of 14.806MJ/kg and a calculated value of 14.198MJ/kg. According to Kittiphop et al (2012)., the ultimate analysis of water hyacinth the elemental composition of C, H, O, N, and S as 29.7 wt.%, 4.52 wt.%, 64.6 wt.%, 0.97 wt.% and 0.21 wt.% respectively. Proximate analysis of water hyacinth showed 20.3 wt.% fixed Carbon, 60.1 wt.% volatiles, 19 wt.% ash and 0.6 wt.% moisture (Kittiphop et al (2012)).

V. WATER HYACINTH AND ECOLOGY

Alterations to water hyacinth density have the possibility of affecting other ecological and human communities in places where it is established; these changes could be negative or positive depending on the intended or advantageous uses of the water body (Gibbons et al., 1994). Water hyacinth is extremely hard to exterminate once established. Therefore, the aspiration of most management efforts is to reduce economic costs and ecological alterations. Recent literature on the management of water hyacinth focuses on techniques to remove the weed; however, little has been done to evaluate the full scope of ecological changes that may crop up in response to the establishment and management of this non-native species. Determining the consequences of controlling an established water hyacinth population is dependent on our ability to comprehend how water hyacinth affects the systems which it inhabits. There are not many studies that report the ecological conditions preceding invasion. This makes it complicated to understand fully how water hyacinth changes an ecosystem.

VI. HISTORY OF WATER HYACINTH INVASION AND MANAGEMENT IN LAKE CHIVERO

"The origins of the noxious weed in this country, is very interesting. It came as a "pot plant" from South America decades ago. The water hyacinth produces very beautiful flowers. By 1937 it was already in evidence along the Mukuvisi River in Harare" (www.worldlakes.org; 2002). Chikwenhere and Phiri, 2010, confirmed that water hyacinth first occurred in Zimbabwe in 1937 and by 1952 it had been noticed on Lake Chivero. In 1953, a year after dam wall construction completed, the first outburst of the invasive weed was reported. Chikwenhere and Phiri, 2010, highlighted that other outbreaks occurred in 1974 and 1986 respectively with the 1986 one continuing up to 1990. Between 1956 and 1990 water hyacinth infestation on the lake's surface area of approximately 25km^2 varied between 15% and 35%.

Zimbabwe's water bodies are being swallowed by water hyacinth at an upsetting rate. Mechanical, biological and chemical methods have failed to control the nuisance of water hyacinth weed which is fast invading and choking the water sources. Water hyacinth is a free-floating perennial weed which forms huge, thick mats on the water surface. Each plant consists of a number of broad, leathery leaves, spongy inflated leaf stalks, a crown and a mass of fine, roots covered with hair. The water hyacinth weed has invaded approximately all rivers, lakes and dams in Zimbabwe and it seems government authorities are relying on research institutions to come up with solutions to deal with this invasive weed. The hyacinth weed was first detected between 1971 and 1972 on Lake Chivero (then well-known as Lake McIlwaine) and a contentious herbicide, 24-D, was used to control it. The herbicide was, however, discarded after studies provided evidence of it being harmful to both human and marine life. The disreputable weed disappeared, only to resurface around 1986 when efforts to hand spray with the chemical, glyphosate, proved unfeasible. Weed barriers were later put up in the upper side of Lake Chivero to stop the untamed plant, but the weed still penetrated the water body. (Sunday mail; 5 May 2012) The Government shifted to importing about 150 000 insects from Australia to feed on the water hyacinth. The pests initially emerged to be an answer, eliminating about 95% of the plant, but regrettably the insects went into extinction as they no longer had something to feed on.

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With the death of the insects, the weed reappeared, leading to the Zimbabwe National Army (ZNA) intervention. The ZNA team's efforts were futile in matching the weed's growth rate and withdrew from the task. Coupled with the economic constrains between 2007 and early of 2009, monetary resources to deal with water hyacinth decreased and the weed blossomed. While efforts are being done to get rid of the weed, experts emphasize that the conflict is almost impossible to win. (Sunday mail; 5 May 2012)

Water hyacinth weeds that would have dried form a carpet on the channel after the spillway at Lake Chivero. The carpet is so dense that people can freely walk on it while water flows beneath. Environmental experts articulate that the high rate at which the country's water bodies are being contaminated is producing encouraging conditions for the plant to survive. According to experts, the water hyacinth weed flourishes in polluted water bodies and nurtures well on excess nutrients made available by pollutants. Water hyacinth is promoted by a lot of chemical nutrients, particularly phosphates and nitrates in marine ecosystems. To solve the predicament, there is need to deprive the water bodies of such nutrients at all means.

VII. WATER HYACINTH MINERAL ABSORPTION

Water Hyacinth has the capability to take up cadmium (Cd) from the bathing medium at the rate of 9.1 μg/l and to help build up metal concentration at the tip of the plant at 6.1 μg/g of dry matter within 24 hours was first shown by Wolverton and Mcdonald, (1979). Chigbo et al. (1982), on the other hand, have shown the remarkable capacity of the plant to absorb relatively high concentrations of metals like As, Cd, Pb and Hg over a short period of time. It has been renowned by different researchers that water hyacinth has the sorption potential of a huge array of metals without itself getting much affected. Pinto et al. (1987) recommended that water hyacinth could be suitably utilized for the recovery of esteemed metals like silver from mine wastes. However, Chatterji argues that water hyacinth has developed into the most common horrible weed found in tropical waters and it is a challenge to the scientists engaged in coming up with methods for its control. (Chatterji, 2005)

VIII. POSSIBLE USES OF WATER HYACINTH

Substantial research work has been directed towards searching of various ways of realising value in the otherwise bothersome Water Hyacinth weed. A number of potential uses of the weed, some of which have been developed and others are still in their infancy have been recommended. These comprise possible utilization of the weed as a phytoremediation agent (Sajn et al., 2005), as a compost (Szczeck, 1999), for power alcohol and biogas production (Mshandete et al., 2004; Ali et al., 2004), as a biosorbent for toxic metals (Malik, 2007), and for animal fodder/fish feed (Aboud et al., 2005). Other prospective uses of the weed incorporate its use as pulp material for making greaseproof paper (Goswami and Saikia, 1994) and the manufacture of fiberboards for a diversity of end uses such as bituminized board for cheaper roofing material, indoor partitioning, and so on. Manufacture of water hyacinth-based medication has been reported in India to treat certain diseases (Oudhia, 1999a, b).

IX. WATER HYACINTH REPRODUCTION

Water hyacinth does both sexual and asexual reproduction and the modes are eaqally important to the species' success as a destructive aquatic intruder. In calm climates, the weeds can flower throughout the year, and from early spring to late fall in other places. Growth rates are explosive and vegetative population doubling can take place in 1-3 weeks (Mitchell 1976, Wolverton and McDonald 1979, Langeland and Burkes 1998).They are capable of yielding an abundance of seeds (Flora of North America 2003, Langeland and Burks 1998) and Shoeb and Singh (2002) highlighted that water hyacinth has a growth rate of 17.5 metric tonnes per hectare per day.

An investigation by Barrett (1980b) confirmed that tropical E. crassipes populations produced twice as many seeds as did moderate populations and ascribed the difference to higher rates of pollinating insect visitation in the tropics. Seed germination has a propensity to take place when water levels are low and the seedlings can grow in drenched soils. Vegetative reproduction occurs via the breaking off of rosettes of clonal individuals. The stolons (horizontal shoots capable of forming new shoots and adventitious roots from nodes) are easily broken down by wave or wind action and floating clonal plants and mats are readily transported by water or wind movement (Barrett 1980a, Langeland and Burks 1998).

X. WATER HYACINTH AND TEMPERATURE

Temperature and nutrients are well thought-out as the strongest determinant factors for water hyacinth growth and reproduction (Wilson et al. 2005). On the other hand, Ramirez argues that salinity limitations generally restrict water hyacinth establishment in coastal areas and within estuaries (Mangas-Ramirez & Elias-Gutierrez, 2004). Although Eichhornia crassipes is excluded from cold climates due to temperature limitations, it does show signs of a degree of freeze tolerance. Aerial sections of the plant killed back by moderate freeze events can speedily re-grow from underwater stem tips secluded from freezing by water (Langeland and Burks 1998).

XI. WATER HYACINTH AND SALINITY

Holm et al. (1977) pointed out that water hyacinth is bigoted of salty conditions. Experimental studies by de Casabianca and Laugier (1995) demonstrated an inverse relationship between salinity and Eichhornia crassipes plant yield. Water hyacinth is capable of growing in low salinity coastal lagoon surroundings such as in West Africa during the rainy season.

XII. WATER HYACINTH'S POTENTIAL TO COMPETE WITH NATIVES

Water hyacinth is capable of changing local resident plant communities by putting out of place native species and altering community structures, biological and ecological systemss. Holm et al. (1977) explained Eichhornia crassipes as one of the nastiest weeds in the world. The ability of water hyacinth to overrun and outcompete aquatic habitat is beyond belief.

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The species can rapidly dominate natural areas and can dramatically alter the species composition, structure, and function of native plant and animal communities (Langeland and Burks 1998). The suspended root structure may account for almost half of the plant biomass. The adventitious roots are clonal plants that break off the parent to instantly flourish on their own and are also able to take root in moist soil in low water environments.

XIII. POSSIBLE ECONOMIC CONSEQUENCES OF INVASION

Large, intense Water hyacinth mats can corrupt water quality and can obstruct waterways. Plant respiration and biomass decay can consequently lead to oxygen depletion and fish kills. The documented harmful economic impacts of water hyacinth incursion worldwide includes the blockage of irrigation channels, choking off of direction-finding routes, clogging of rice paddies, loss of fishing spots, amplification in breeding habitat to disease-transmitting mosquitoes. The costs connected with elimination and maintenance control of water hyacinth are quite considerable.

XIV. BIOGAS TECHNOLOGY SITUATION IN ZIMBABWE

The Government of Zimbabwe through the Ministry of Energy and Power Development has been promoting domestic biogas technology using animal waste. Nothing has been done with regards to using water hyacinth. Other organizations which complimented the efforts of the Ministry were Silveira House, Biomass Users Network and the Agricultural Engineering Institute among others. Common bio-digester designs which were promoted were the Chinese and the Indian type. However the Indian type was found to be more expensive than the Chinese because of the metal gas holder.

The failure rate was also noticed in China and India for the same reasons (Karekezi and Ranja, 1997), however in Nepal the implementation of the technology recorded a success. According to Karekezi and Ranja, (1997) the success was due to the commercial market based approach to the biogas programme. The biogas programme was multidisciplinary in approach involving sectors such as agriculture, health, finance and NGOs. There were vigorous information and publicity programmes as well as credit facilities and subsidies were given through banks. Table 1 shows methane production from sewage plants in some cities in Zimbabwe.

Table 1: Methane Production from Sewage Plants using Bio-digesters in Zimbabwe

City or Town	Sewage (m^3/day)	Biogas (m^3/day)	Methane (m^3/day)
Harare Crowborough	940	23,500	8,500
Harare Firle	1,800	46,500	17,000
Mutare	30,000	1,107	554
Masvingo	16,800	621	311
Bulawayo	35,000	2,951	1,475

Source: Zimbabwe Country Study (2001)

XV. BIOGAS PRODUCTION FROM WATER HYACINTH

A study carried out by Almoustapha et al., 2008, revealed that it is possible to produce biogas from a mixture of water hyacinth and fresh rumen residue. Chanakya et al, 1993; Kivaisi and Mitla, 1998; Singhal and Rai, 2003; Kumar, 2005 as well as Kunatsa et al, 2013 among other authors confirmed the possibility of producing biogas from water hyacinth. Almoustapha et al, 2008, highlighted that biogas outflow is related to seasonal variations in temperature. For the same retention time, the total volume of biogas obtained during the warm season is 1.8 times greater than that obtained during the cool season.

According to Nijaguna (2002), aquatic plants generate high-quality biogas but their salinity of 35-50 parts per 1000 is a serious problem. Water hyacinth generates biogas that has greater methane content and more soil nutrients than digested dung. Nijaguna highlights that water hyacinth produces 20.3 liters of biogas per kg of dry matter. On the other hand, Dr.A.Jagadeesh 2012, noted that a hectare of water hyacinth can produce enough biogas each day to generate between 90 and 180 cubic meters of methane, equivalent to 3.44 to 6.88GJ of energy production.

Urban areas like Harare have been seriously affected by energy challenges and yet these areas have the potential of producing large amounts of biogas as they are situated near lakes such as Lake Chivero which have the feedstock for biogas plants in the form of water hyacinth. Despite the serious drawbacks, water hyacinth invasions in lakes can be harnessed for environmental benefit and renewable energy production. Water hyacinth has a very high cellulose content making them a potential renewable energy source. While controlling water hyacinth populations has proven to be beyond the capabilities of local government, using these plants for energy production provides an alternative approach to dealing with this invasive species. Water hyacinth can be used to produce biogas, an energy source that already has been embraced world over.

An investigation into the possibility of bio-converting water hyacinth to yield biogas adds value and solves the problem of water hyacinth management as well as gives a solution to the energy and power shortages since people would no longer rely on the expensive LPG nor grid electricity. Biogas will lead to reduced use of fuel wood and diesel generators hence an innovative technology to the reduction of greenhouse gas emissions. Beside of energy production, other valuable products, such as high quality bio-fertilizer are obtained from the anaerobic digestion of water hyacinth and this will minimize the use of expensive mineral fertilizer. The option of biogas production as a way of energy exploration using water hyacinth may not only sustain the energy availability but also improve environmental sustainability by improving the social, economic and physical well being of the environment.

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1. *Feasibility study of Biogas production from Water Hyacinth. A case of Lake Chivero–Harare, Zimbabwe*; **Kunatsa T** , Madiye L, Chikuku T, Shonhiwa C, **Musademba D** - International Journal of Engineering and Technology Volume 3 No. 2, February, 2013 pge 119-128
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