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Jatropha as energy potential biofuel in Tanzania

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ABSTRACT

People living in the large part of the African, Asian and Latin American continents often lack access to energy sources in general. One approach to provide these people with energy to increase living standards is to enable them produce energy from local resources. A promising local renewable energy source for people living in tropical regions is *Jatropha curcas* (Linnaeus), in which biodiesel can be sourced from its fruits. The byproducts from biodiesel are of potential as well in renewable energy sources. Energy contribution from by products include the utilization of fruit shells briquettes as an energy source, production of chemicals from biofuel byproducts such as gryceline, biogas production from the press cake.. Biomass serves as the major source of energy in Tanzania providing about 90% of the total energy consumed and energy from oil and gas provides about 7% of the consumed energy. The results from two scenarios in this study indicated a positive contribution of the Jatropha bioenergy system to the energy sector in Tanzania. Jatropha press cake biogas alone has a potential to contribute 25% to 134% of the national annual electricity per capita by the year 2015, while adding more than 50% oil obtained after pressing of Jatropha seeds. However, biofuel investment and production is a highly contentious issue. Critical aspects to consider on Jatropha cultivation in Tanzania include water distribution and usage, food security, environmental conservation and biodiversity, social impacts and economic issues. Lastly, this study concludes that biorefinery of Jatropha products will offer more energy contribution, wastes reduction and more value to Tanzania biofuel industry, particularly Jatropha bioenergy system.

Keywords: Jatropha, Press cake, Biogas, Energy source, Tanzania.

1. Introduction

Sustainable energy production and supply are strategic objectives for developed as well as developing countries. The energy sector plays a crucial role in attaining the United Nations Millennium Development Goals (Short, 2002), and the sustainability of modern economics is based in part on the capacity of countries to ensure their energy supplies. This is especially true for the transport sector, which consumes 30% of the world energy production, 99% of which is petrol-based (IEA, 2008). Global energy supply is currently mainly based on fossil fuels, which have many disadvantages. It is now widely agreed that more sustainable alternative energy sources will need to be developed. One potentially promising option consists of biofuels, since these are derived from biomass, have a closed carbon-cycle and do not contribute to the greenhouse effect. The biomass necessary for the production of biofuels can be derived from several sources; oil-producing crops are prominent among these. Current biofuels are actually based on traditional food crops such as maize, rapeseed or sunflower. A wide range of energy and global greenhouse gas budgets has been reported for them,

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although they are generally favourable compared with conventional fossil fuels like gasoline and diesel (Hill et al., 2006). However, these types of feedstock raise concerns because they are directly linked to food security issues. Also their cultivation is fuel-fertilizer and pesticide-intensive, with significant impacts on ecosystems.

Although Jatropha grows naturally in Africa, its cultivation on an economic scale is a recent venture for which little reliable scientific data exists either for environmental assessment or management. At present, the main agro-environmental impact studies in East African countries are largely qualitative, this include countries like Kenya (Kalua, 2008) and Tanzania (Eijck and Romijn, 2008). In Tanzania, the development of Jatropha biofuels is still in an early phase, and that its future is still unclear. Despite the favourable constellation of many contextual 'landscape' factors, there remain prominent barriers within Tanzania's existing energy regime (Eijck and Romijn, 2008). This study aims to evaluate the Jatropha curcas L. as energy source biofuel and reports the results on the production and energy potential of biogas from Jatropha press cake in Tanzania.

2. Methodology

2.1 Jatropha production, use and its application

Tanzania is globally placed to be the leader in biofuel production because of having ideal geographic and climatic conditions for growing a wide range of bio-fuel crops such as sugar cane, palm oil, Jatropha, soy bean, and cotton. Jatropha is well promoted in Tanzania and investments have been reported to increase with strong political support. Currently, estimation for planted Jatropha in Tanzania is 17,000 ha which is 1.9% of the global cultivation and 14.4% of the total cultivation in Africa. Tanzania is considered very important for Jatropha cultivation sector with an estimate (GEXSI, 2008) of up to 69,870 ha in 2010 to 620,110 ha in 2015.

Table 1: Comparison of calorific value of Jatropha oil and seeds to conventional fuels

Parameter	Gross** calorific value (MJ/Kg)
[a]Jatropha seed	20.852 ± 0.08
[a]Jatropha press cake	18-25.1*
[a]Jatropha oil	37.832 ± 0.08
[a]Gasoline	47.127
[a]Crude oil	44.091
[b]Diesel fuel	46
[b]Kerosene	47
[b]Wood (15% water)	16
[b]Cooking coal (1-4% water)	35-37
[b]Coal (general purpose and 5-10% water)	32-42

Source: [a] Augustus et al., 2002 and [b]www.kayelaby.npl.co.uk
*depends on residue oil content in the press cake
**water formed and liberated during combustion is in the liquid phase

The plant *Jatropha curcas* (Linnaeus) belongs to the family Euphorbiaceae and is indigenous to Latin America and naturalized throughout tropical and subtropical parts of Asia and Africa. When people use the term Jatropha, usually they refer to this species which is one of the 170 known species of this wild plant (Akintayo, 2004; Jongschaap et al., 2007). Jatropha being a woody plant can be used for a number of purposes and in Tanzania the common uses of

Jatropha include hedging, solid fuel, medicines, marking grave yards, supernatural beliefs, soap making, fertilizer and biogas production (Jongschaap et al., 2007; Fleuret, 1980; Heller, 1996). Of the various applications of Jatropha, transport fuel is probably the most promising for the Jatropha seeds from both an economical and ecological point of view. The potential work that a fuel can do is determined by its energy content (Singh et al., 2008). The calorific values of solid and liquid Jatropha fuels as compared to those of conventional fuels are shown in Table 1.

2.2 Jatropha biofuel by-products

The by-products of fresh Jatropha fruits include the shell, the hull, and the press cake. The fresh Jatropha fruit contains about 35–40% shell and 60–65% seed (by weight) of which 40–42% husk/hull and 58–60% kernels which consists of about 50% oil. The fruit shell is reported to contain about 34% cellulose, 10% hemi cellulose and 12% lignin and is good in minerals (Singh et al., 2008). In Tanzania is common to press the oil from peeled fruits and the shells are obtained after peeling the fruits leaving the seed with 100% hull to be pressed. Scientific investigation on the shell reveals its potentials for biological conversion and energy source as powdered briquettes and it high ash content (14.88%) a potential for fertilization of the soil. Using an up flow anaerobic digester filter, biological conversion of the shells after pre-treatment to remove fibres was possible producing biogas with 70% methane. Despite all that the shell briquettes still offers a more green energy opportunity for domestic and industrial fuel (Singh et al., 2008).

The Jatropha seed hull/husk is known to contain 3.97% ash, 71.04% volatile matter and 24.99% fixed carbon on dry weight basis, 10% moisture and the calorific value of 4044 $kcalKg^{-1}$. Laboratory gasification of the husks reached a maximum efficiency of 68.31% at a gas flow rate of 5.5 m^3h^{-1} and specific gasification rate of 270 $Kgh^{-1}m^{-2}$, at this point the calorific value of the gas is 1105 $kcalm^{-3}$. Biological conversion can be possible as well due to its high content of organic matter and this one contributes much to the Jatropha press cake organic matter because husks is left with the seed for pressing. Currently, the seed hull can not be counted separately as a source of energy since it part of the press cake.

The Jatropha press cake is obtained after separating the oil from the other seed contents chemically or mechanically. In Tanzania oil is obtained mechanically using a ram press or a screw press. Jatropha press cake in Tanzania is used as fertilizer, animal feed, source of biochemical and biogas production for energy source. Jatropha press cake can be used as organic manure, it nutrient content is richer than cow dung and neem cake and comparable to chicken manure. It contains macroelements nitrogen, phosphorus, potassium, sulphur and micronutrients Fe, Mn, Zn and Cu in a range from 800 to1000, 300 to 500, 30 to 50 and 18 to 25 $mgKg^{-1}$ of respectively. Jatropha press cake has also a nitrogen content of up to 6%, similar to that of castor beans and chicken manure. These increase the yield of Jatropha seeds up to 120% over the control without manure treatment. The great hope behind many growers of Jatropha in Tanzania was to utilize the press cake for animal feed and selling to gain income. This has been a declined hope due to the fact that the Jatropha species grown in the country as of many parts of the world is toxic and yet the detoxification of cake is not of economically achievable and profitable at least at large scale. Therefore, the cake is only used as fertilizer and for energy source as briquettes or biogas production raw material (Janssen et al., 2005). Jatropha seed cake a source biochemicals and considered a best carbon sources among various carbohydrates, because it is pure, inexpensive and can be available in a mass supply. It has also been reported as good feed stock for production enzymes used by food industry (Muralidhara Rao et al., 2007).

3. Results and discussion

3.1 Energy potential of biogas from Jatropha press cake

Jatropha press cake is a good feedstock for biogas production because it is rich in organic matter; containing between 56%-64% crude protein (Benge, 2006). Biogas production from Jatropha press cake is about 60% higher as compared to the biogas generated from cow dung and had better calorific value as it had more methane (Lopez et al., 1997). More scientific investigations for anaerobic digestions of Jatropha press cake is required in order to draw a conclusion on its potentials to contribute as energy source. Basics of the biogas process: Fermentation of organic matter by Microorganisms, allows the decomposition of organic matter aerobically or anaerobically. In aerobic decomposition the end products are carbon dioxide, heat and humus, during which most of the energy is lost as heat and production of new biomass. In anaerobic decomposition the main products are methane, carbon dioxide and peat or manure or sludge depending on the nature of process and the raw materials. When methane is produced under natural fossil conditions the gas produced is called natural gas. Biogas is normally produced through the process known as anaerobic digestion in swamps, marshes and intestinal tract of ruminant animals. Anaerobic digestion can be defined as the symbiotically stepwise process by which organic matter is digested to mainly methane (CH_4) and carbon dioxide (CO_2). It is a process due to concerted action of several metabolic groups of micro-organisms (Figure 1).

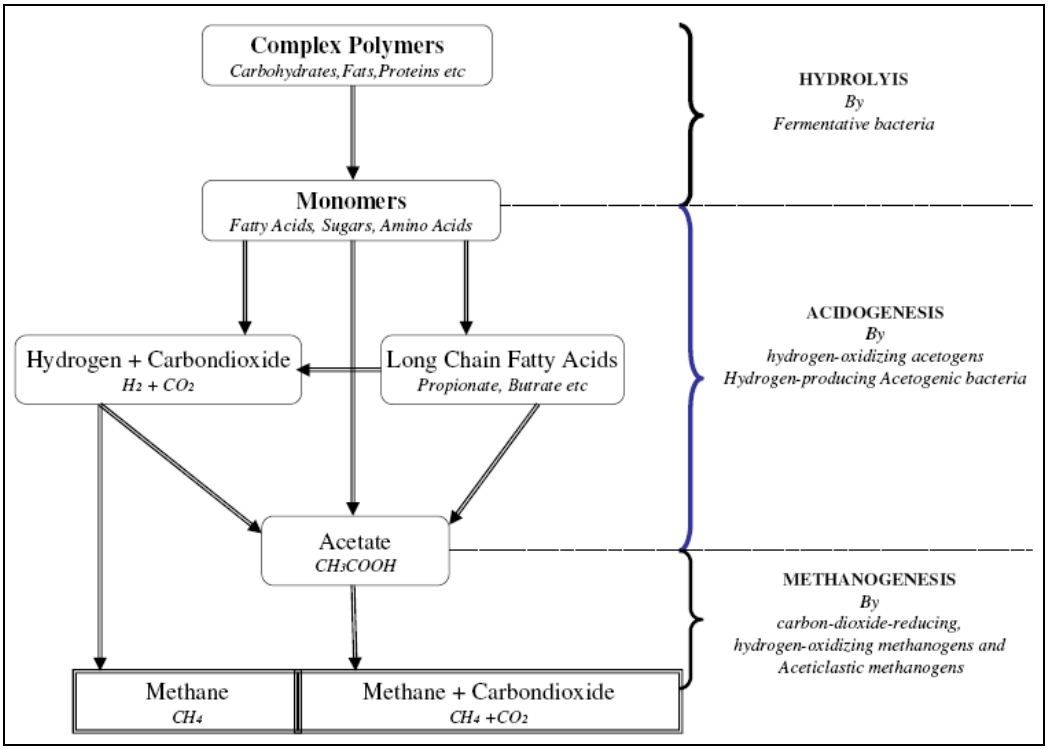

Figure 1: Anaerobic digestion process

Biogas composed of a mixture of different gases including methane (50-75 Vol.%), carbon dioxide (25-50 Vol.%), hydrogen sulphide (50-6000 ppmv), Nitrogen (0-5 Vol.%), Ammonia (0-1 Vol.%), Oxygen (0-2 Vol.%), hydrogen peroxide (1-10 Vol. %) and water vapour (0-1

Vol.%) (Singh, et al., 2008). The contents of the gases will depend on the type of the material composition of the organic matter used as feedstock and the process parameters and conditions during fermentation. The major difference between natural gas and biogas is the methane content and so it implies to their energy quality. The methane content is giving the energy quality of the gas and hence determines its application. The methane content of the biogas is usually measured at 50% to 80% by volume of the produced gas.

Process parameters and conditions: During the anaerobic digestion process parameters like pH, temperature and content of secondary gases in the digester must be controlled (Lopez et al., 1997; Wulf, 2005). Higher pH, value of the medium will allow gases such carbon dioxide and hydrogen sulphide to remain dissolved in the median and so methane yield is higher in the biogas produced. However, too high medium pH will again lead to accumulation of organic acids which can lower the pH of the medium. Because the methanogenic bacteria are pH sensitive, pH less than 6 and above 8 will limit the functioning and hence lower the production of methane most of the time, the buffer system is used to make the system stable throughout the process. Biogas producing can work at either psychrophilic (below 20 ^{o}C), or mesophilic (room temperatures/ above 20 ^{o}C to 42 ^{o}C) or thermophilic conditions with temperatures between 42 ^{o}C -55 ^{o}C. However most of the bacteria work best at mesophilic conditions. At very low temperatures the microorganisms are very slow and the residence time can go up to 3 months. At thermophilic conditions the digestion is very fast (15-20 days) but the process becomes very temperature sensitive and promotes the volatile fatty acids formation. Sulphide content and ammonia gases content during digestion differs depending on substrate used, proteins high sources always can give higher sulphide and ammonia gases due to decomposition of protein, these can be controlled by pH stability and then the gas is purified or can be removed by additives, example sulphide can be removed by addition of iron salts in the medium.

The amount of biogas yield from anaerobic digester: This will depend on (1) The substrate composition: Simplicity for degradation by type of microorganisms depends on structure components of the substrate ingredients (Wulf, 2005). Theoretically samples such as waste fat, grease and oils containing more fat/lipid contents yield more biogas and with high quality for different application relative to others under certain conditions. The rate of digestion always depends on the structure complexity of the substrate and it should not be confused with the yield. Carbohydrates such as sugars are easily degradable than starch or protein so the protein will take more time to digest. On the other hand substrate like cellulose and hemicelluloses are even harder to degrade while the lignin is even not degradable (Wulf, 2005). (2) Organic Total Solids (oTS): The amount of degradable material will determine the amount of biogas produced. In continuous process organic loading rate (KgoTS/m^{3}day) determines the yield. When the process can accommodate a high organic loading rate then this can imply higher yields. However on the other hand if the concentration of the organic total solids is too high, microoganisms can have a problem of adaptation and hence affects the yield and/or the retention time. Depending on the process and type of substrate, organic loading rate differs (Sawe, 2007).

3.2 Jatropha availability scenarios

Two scenarios of Jatropha press cake availability are considered depending on the GXSI report (GEXSI, 2008) on Jatropha cultivation in Tanzania; experts' scenario as scenario 1 and GXSI scenario as scenario 2 (Table 2). In the scenario 1 the area estimated to be under cultivation is 11700, 34300 and 116000 for 2008, 2010 and 2015 respectively. For the scenario 2 the area identified under Jatropha cultivation is 17000, 69870, 620110 ha for 2008, 2010 and 2015 year respectively. Assuming that 6 T/ha constant yield of seeds per ha to 2015, 75% of the seed remain as press cake after pressing the oil, 4kg of seed gives 1L of oil and the 3Kg remains as press cake. The press cake is 100% available for biogas production, characterized by 92% oTS and 92% TS, biogas production is at 350 L/KgoTS with 65% methane. The proper technology is used resulting to efficient production and power losses during transmission are negligible.

Value added to 1L of oil pressed: One litre of oil is obtained by pressing 4 kg of Jatropha seed, leaving 3kg of press cake as a by-product. Biogas production from this cake will produce 578 L of biogas which is worthy 20.8 MJ of energy. Comparing to the energy value of 1 L of Jatropha oil which is 40.7 MJ, the value added is 51%. This will improve the Jatropha bioenergy system and contribute significantly in sustainability of Jatropha bioenergy system exploitation in Tanzania.

Table 2: Energy potentials of the Jatropha press cake in two scenarios

Scenario	**Year**	**Area under Jatropha cultivation (ha)**	**Amount of press cake ($Tx10^3$)**	**Methane produced (m^3)**	**Equivalent energy potentials**		
					GJ	**MWh**	**BEO**
Scenario 1	2008	11,700	52	1.0×10^7	3.7×10^5	1.0×10^5	6.0×10^4
	2010	34,300	154	3.0×10^7	1.0×10^6	3.0×10^5	1.7×10^5
	2015	116,000	522	1.0×10^8	3.6×10^6	1.0×10^6	6.0×10^5
Scenario 2	2008	17,000	77	1.5×10^7	5.3×10^5	1.5×10^5	8.7×10^4
	2010	69,870	314	6.1×10^7	2.1×10^6	6.1×10^5	3.6×10^5
	2015	620,110	2790	5.4×10^8	1.9×10^7	5.4×10^6	3.2×10^6

Contribution to National Energy Sector: The annual per capita electricity consumption in Tanzania was estimated to be about 80 kWh in 2005 while the annual energy consumption per capita was 29,300 MJ. Having these data as constant base values, with efficient exploitation of Jatropha press cake and use of the gas as energy source would contribute significantly to the energy sector in the country especially in rural areas with decentralization of the electricity distribution system. With scenario 1, there is a potential of 3.7×10^5 GJ existing currently which is mainly utilized as fertilizer and little biogas substrate in households, this potential is to be expected to increases up to 3.6×10^6 GJ in 2015. In scenario 2, the current potential is which 5.3×10^5 GJ which is 43% higher compared to the first Scenario. This as well is expected to increases up to 5.4×10^8 GJ in 2015 which is 500 times higher compared to the same in scenario 1. This energy amount can be used as source of heat for cooking at household level, or to generate electricity. The contribution of the energy in terms of Barrel Equivalent of Oil (BEO) in both scenarios ranges from 0.06 to 3.2 Million BEO per year which is equivalent to foreign exchange saving of 2-128 days due to importation of crude oil barrels. These energy potentials will therefore contribute to environmental conservation due deforestation, accelerate national development by increasing the number of Tanzanians with access to electricity; allowing small scale investments and business projects, these are directly linked to the millennium development goals and available national development strategies. However still this will need more research input in order to efficiently exploit the potentials.

For scenario 1, the potential for contribution to national annual electricity per capita is 134%, which is equivalent to 1.65% of the national total annual energy per capita in 2015 (Figure 2). The corresponding values were 4% and 0.05% in 2008 and 15% and 0.19% in 2010. The energy can be exploited more efficiently at local levels to avoid power loss due to long distances and lack of capacity. In scenario 2, if the biomethane potentially produced is converted to electricity and fed in to the national electricity grid, it has a potential to contribute up to 25% in 2015 in the annual national electricity per capita, this contribute 0.31% of the total national annual energy per capita (Figure 3). The corresponding values were 3% and 0.003% in 2008 and 7% and 0.09% in 2010.

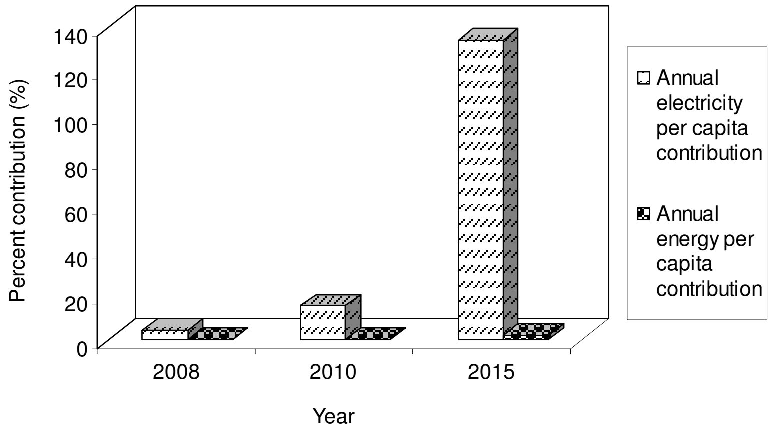

Figure 2: Potential biogas contribution to Tanzania annual energy and electricity per capita in scenario 1

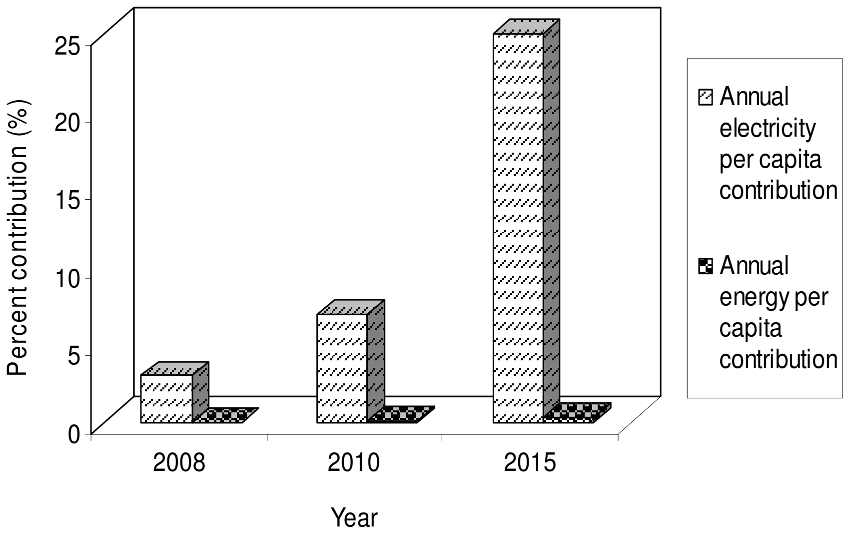

Figure 3: Potential biogas contribution to Tanzania annual energy and electricity per capita in scenario 2

3.3 Critical aspects and best practice for sustainable exploitation of Jatropha

The Government of Tanzania and international donors have identified biofuel as a priority growth sector and aimed at providing extensive support for investments in this sector. The hesitation is well revealed in the areas of land provision for biofuel crop cultivation though the country is politically stable and has favourable environment for business. On the other hand as the biofuel policy is not in place, government deferred new biofuel projects registration as it prepares a national policy on biofuels (Sawe, 2007). Though the biofuel issues are discussed very generally, it is worth noting that the pros and cons of the oil crops differ in many ways. The more focused biofuels crops in Tanzania include Jatropha, sugar cane, sisal and palm oil this paper focuses on the Jatropha this section focuses on the Jatropha. Billed as wonder crop, the establishment of Jatropha plantations on the ground in Tanzania has been far from successful, or, in some cases, ethical. Biofuel investment and production in Tanzania is a highly contentious issue but aspects and/or issues such as water distribution and usage, food security, environmental conservation and biodiversity, social impacts and economic issues should critically be considers on Jatropha cultivation in Tanzania (Soares Janssen et al., 2005; Jongschaap et al., 2007; Severion et al., 2007). Biofuel investors have been doing business in Tanzania since 2000, but business stepped up a gear after 2006. To date there are 17 investor companies, from UK, Germany, Sweden, the Nederland and America have shown interest of acquiring land for Jatropha cultivation. Other Local institution and NGOs promoting Jatropha use in Tanzania include Tanzania Traditional Energy Development and Environmental Organization (TaTEDO), The Company For Technology Dissemination and Training (KAKUTE Limited-"Kampuni ya Kusambaza Teknolojia") and Tanzania Industrial Research and Development Organisation (TIRDO) (Sawe, 2007). This is a small number of investors compared to those in Brazil and Indonesia, but a number with clear motives. With over four million hectares requested by investors for biofuels only 650,000 hectares currently allocated, this is a sizeable potential earner for Tanzania (Sawe, 2007; Alweny, 2008).

Biorefineries are facilities that integrate biomass conversion processes that produce fuels, power, and chemicals from biomass. Biorefineries involves producing multiple products, taking advantage of the differences in biomass components and intermediates and maximize the value derived from the biomass feedstock. Using the concept of biorefinery therefore, it is possible to reduce amount of and increase safety of waste products, increase economic effectiveness of biomass source and valorisation of all plant material to useful and high value products (Zinoviev et al., 2007). There is clear indication that the Jatropha system in Tanzania can adopt the biorefinery concept as the industry is growing very fast with full support from investors, government and local people. The biorefinery concept could significantly reduce production costs of plant-based chemicals and facilitate their substitution into existing markets.

Possible more use of the Jatropha by-products includes the utilization for biodiesel, production of chemicals, soap and lubricants and also utilization of Jatropha shells as an energy source, biogas production residues as fertilizers and biogas as fuel in engines, Jatropha press as substrate for enzyme production and platform chemicals (Figure 4). The biggest challenge in the exploiting the biorefinery concept are lack of experience and knowledge (best practices) on the Jatropha system i.e. still a young industry, lack of research to avail proper technologies and processes proper in the context of Tanzania, lack of capital, lack of biofuel policy and lack of local expertise.

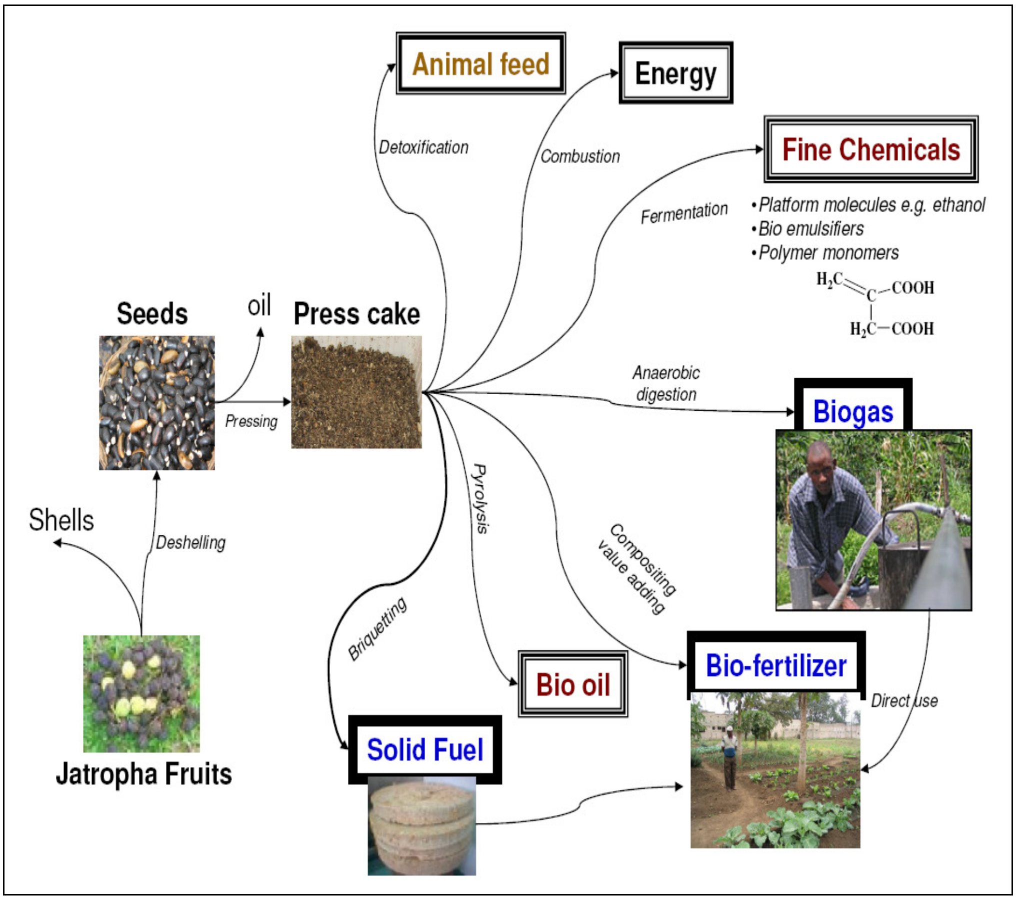

Figure 4: The valourisation of Jatropha press cake for biorefinery potentials

5. Conclusion

The principle though originally focuses on risks for Jatropha large scale plantations but it fevers poverty reduction and the fulfillment of the millennium development goals (MDGs) in general (World Bank, 2006). Countries like Tanzania also aims to reduce poverty of her people but the environment the element of planet should be conserved and considered when biomass is utilized. On the other hand there is no business without profit then the investors have to be careful before and during investment. In Tanzania there are great opportunities for Jatropha biofuel industry and the biofuel industry in general. These include the land availability, supportive climatic conditions, water availability, political and peoples will and the need of the industry and its potentials towards attaining the MDGs. Already the short-term experience in Jatropha investment shows promising potentials in exploiting the products of Jatropha. Biofuel is an inter-sectoral industry; the success and sustainability of the industry in Tanzania will sorely depend on policy to be put in place. It is hereby highly recommended to take the precaution as the industry grows very fast. In order to fully exploit the Jatropha products sustainably in Tanzania the following areas has to be seriously considered for advance:

1. Speeding the formulation of biofuel policy by-products valourisation, oil production and blending. The biofuel policy will determine the investment environment and market for Jatropha but also pave a way for technology expansion and technology transfer.

2. Research collaboration in the areas of technology and production with local institutions such Sokoine University of Agriculture (SUA) and other university and NGOs to fever the improvement of the local expertise and sharing of knowledge for the sustainability of the biofuel industry and specifically Jatropha system.
3. Improvement of top down information and knowledge flow in order to facilitate the MDGs goals fulfillment and reduce conflict. Also improvement of technical know how for mainstreaming and multiplication of technology

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