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INAUGURAL LECTURE SERIES 22

LADOKE AKINTOLA
UNIVERSITY OF TECHNOLOGY
OGBOMOSO, NIGERIA

NO FREE LUNCH:
IMPLICATIONS OF THE FARM AS A THERMODYNAMIC SYSTEM

PROF. SIMEON OLATAYO JEKAYINFA

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IMPLICATIONS OF THE FARM AS A THERMODYNAMIC SYSTEM

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By

SIMEON OLATAYO JEKAYINFA

B,Eng (Ilorin), M.Sc., Ph.D (Ibadan), MNSE, MNIAE, MIAgE, MASABE, R.Eng., FASI

Professor of Farm Power and Machinery

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NO FREE LUNCH: IMPLICATIONS OF THE FARM AS A THERMODYNAMIC SYSTEM

Courtesies
The Vice-Chancellor,
Registrar,
Other Principal Officers of the University,
Provost of the College of Health Sciences,
Deans of Faculties and Postgraduate School, especially Dean, Faculty of Engineering and Technology,
Professors and other members of Senate,
Heads of Departments, especially Head of Department of Agricultural Engineering.,
My Academic Colleagues,
The Congregation and Other Staff,
My Lords Spiritual and Temporal,
My Special Guests, Friends and Well-Wishers,
Gentlemen of the Print and Electronic Media,
Greatest Ladokites,
Ladies and Gentlemen

I return all glory, honour, dominion and power to the Lord Almighty Who ordained that I stand before you today, 10th day of May 2018, to present the 22nd Inaugural Lecture of this great University. It is the second in the Department of Agricultural Engineering and the fourth in the Faculty of Engineering and Technology.

Preamble
Permit me, Mr Vice Chancellor, to begin this Inaugural Lecture with a passage from the Holy Scriptures, and I quote:

"In whom are hid all the treasures of wisdom and knowledge."(Colossians 2:3)

One of the attributes of God that is very amazing is His omniscience. He not only understands all the intricacies of very hard science, He ordained them in the first place! The same applies to every other discipline of study and activity.
Therefore it is my strong belief that no successful research, achievement or breakthrough is ever possible without special insight from God. He is the Alpha and Omega of every endeavor in life. The content of this lecture is, by no means, an exception. To Him who created all, knows all and gives all, be all glory, honour, praise and adoration, forever and ever. Amen!

How it all began
I have been privileged to have had practical experiences as a practicing Agricultural Engineer before becoming a teacher of Agricultural Engineering. I started my professional journey at the Bakolori Irrigation Project, Talata Mafara, Sokoto State (in the present Zamfara State) in 1988 as a maintenance Engineer. Later, I briefly participated in the opening of some rural roads in the old Oyo State before getting a full appointment as an Executive Agro-processor with Oyo State Agricultural Development Programme (OYSADEP), where I rose to become a Senior Agricultural Engineer. In OYSADEP, I was involved in the fabrication and installation of agro-processing equipment and storage facilities for needy farmers throughout the old and new Oyo States. My journey towards a career as a lecturer of Agricultural Engineering started after leaving OYSADEP but not without the push from my mother, Professor (Mrs) A.A. Jekayinfa, who prayerfully secured a lecturing appointment for me in the Department of Mechanical Engineering, here in LAUTECH. I was with the Mechanical Engineering Department for five years until year 2004 when the Department of Agricultural Engineering was carved out and I became the pioneer Head of Department. The rest, as they say, is history, as by the special grace and guidance of God, I rose from Lecturer II to Professor with effect from 1st October, 2010.

Mr. Vice-Chancellor, Sir, permit me to recap some facts on inaugural lectures from the inaugural lecture of John Adesiji Olorunmaiye titled, “Energy Conversion and Man”, delivered on May 24, 2012 at the University of Ilorin: The history of inaugural lectures dates back to 1708 when Thwaites, an English Professor of Greek delivered the first inaugural lecture. It is the tradition in Universities that Professors are invited to give an inaugural lecture which provides an opportunity to showcase their work to the wider public. It is also a celebratory occasion when the Professors can also share their achievements with colleagues, family and friends. Hence inaugural lectures are a valued tradition within Universities. The inaugural lecturer may choose to focus on his/her research work and his/her area of specialization or, he/she may decide to discuss broad issues of his/her profession.
Mr. Vice-Chancellor, Sir, today I intend to combine the two. This lecture is therefore titled: “No Free Lunch: Implications of the Farm as a Thermodynamic System”.

No Free Lunch!

Be not deceived; God is not mocked: for whatsoever a man soweth, that shall he also reap (Galatians 6:7)

If any would not work, neither should he eat (2 Thessalonians 5:10b)

"There is no such thing as a free lunch" is a popular saying to communicate the notion that it is impossible to get something for nothing. The "free lunch" in the saying is about the practice in American bars in the nineteenth-century where drinking customers, who had purchased at least one drink, were enticed with a “free lunch”. Because many of these foods on offer were high in salt (e.g., ham, cheese, and salted crackers), so those who ate them ended up buying a lot of beer (Heinlein, 1997). It is an acknowledgement that in reality a person or a society cannot get "something for nothing". Even if something appears to be free, there is always a cost to the person(s) involved or to society as a whole, although it may be a hidden cost or an externality.

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Coming home to the sciences, "**No free lunch**" means that the universe as a whole is ultimately a closed system. There is no magic source of matter, energy, light, or indeed lunch, that does not draw resources from something else, and that will not eventually be exhausted. The slogan: “**No free lunch**" may therefore be applicable to natural physical processes in a closed system (either the universe as a whole, or a system that does not receive energy or matter from outside) as in second law of thermodynamics. The “No Free Lunch” or “You cannot get something from nothing” statement can be regarded as the vernacular version of the first law of thermodynamics: The total heat energy added to a system equals the increase in internal energy minus any work done by the system. This is equivalent to the principle of conservation of energy. “No free lunch” refers to the reality that even some of the most environmentally friendly implications still have negative effects. There is nothing that is purely ‘green’ because there will always be some negative side effects (Carroll, 2018).

The Farm

The farm is where the totality or some of agricultural operations are being carried out. These include crop and animal production, crop and animal processing and storage, the farmhouse and other agricultural buildings as well as the land. It is an area of land that is devoted primarily to agricultural processes with the objective of producing food, fibres, fuels and other crops. In modern times the term has been extended so as to include such industrial operations as wind farms, fish farms and cottage processing mills.

Every stage of farming requires the use of equipment and machinery that consume energy. At present, fossil fuels, in the various forms, supply most of the energy required by agriculture (Sandell et al. 2014). In Nigerian mechanized farms, common energy sources for agriculture include petrol, diesel, and electricity (Jekayinfa, 2006). Fossil fuels are currently used to operate tractors and other farm machinery. Fuels are also required for the transportation of fertilizers, crop seeds and other goods to and from the farm. Electricity is a common power source for agriculture. Electricity is mainly used for water pumping for cleaning, animals drinking and crop irrigation; stationary operations including electricity uses for various machines and appliances including heating, cooling and ventilation (Jekayinfa et al., 2003a) and also for the farm houses. Energy is used both on-farm and off-farm in agriculture (Saunders et al. 2006; Chen et al. 2010). It may be further divided into direct energy use, that is, the fuel and electricity consumed during agricultural production, and the indirect energy (embodied energy) involved in the production of all other inputs from equipment to agro-chemicals (Fig.1) (Sandell et al. 2014). For the livestock industry, this could include the feed purchased from outside the farm (Chen et al., 2015).

A Thermodynamic System

Thermodynamics deals with the science of "motion" (dynamics) and/or the transformation of "heat" (thermo) and energy into various other energy– containing forms. The flow of energy is of great importance to engineers involved in the design of the power generation and process industries. Thermodynamics provides an understanding of the nature and degree of energy transformations, so that these can be understood and suitably utilized.

Certain quantity of matter or the space which is under thermodynamic study or analysis is referred to as system (Nag, 2014).

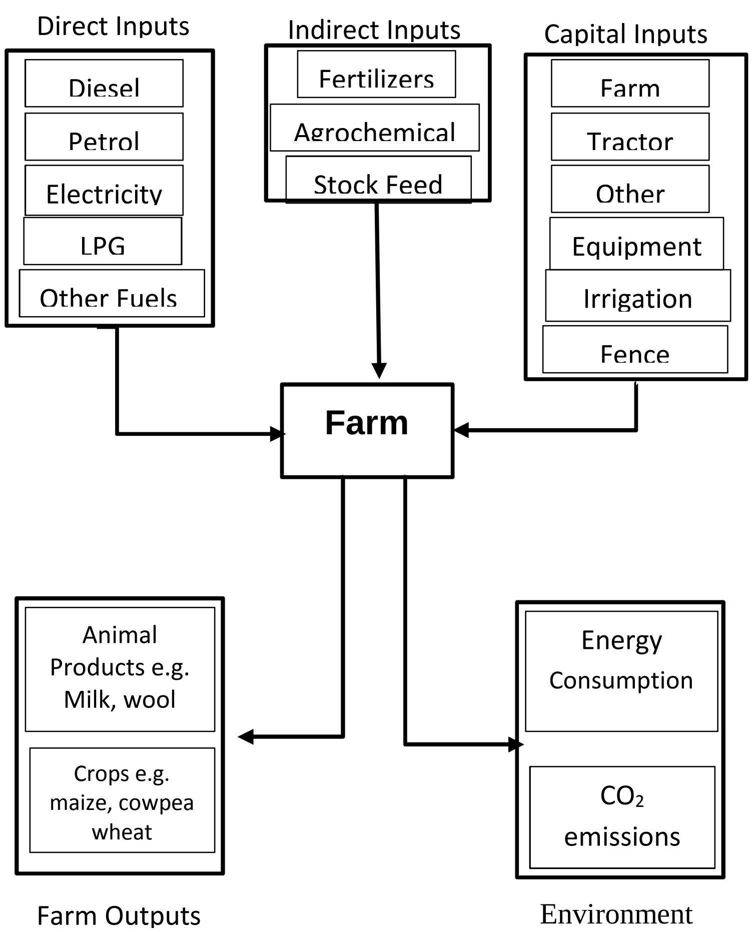


Fig. 1: Various inputs of farm production
***Source*: Saunders et al. (2006)**

There are three mains types of system: open system, closed system and isolated system.

1) **Open system**: The system in which the transfer of mass as well as energy can take place across its boundary is called an open system.
2) **Closed system**: The system in which the transfer of energy takes place across its boundary with the surrounding, but no transfer of mass takes place is referred to as closed system. The closed system is fixed mass system.
3) **Isolated system**: The system in which neither the transfer of mass nor that of energy takes place across its boundary with the surroundings is called an isolated system.

The Farm as a Thermodynamic System

Because of its nature, a farm can be regarded as an autocatalytic (self-organizing), thermodynamic system that converts photosynthetic energy to energy in the form of crop yield (Jordan, 2016). First law of thermodynamics simply states that energy or matter can neither be created nor destroyed but it can change forms. The energy transformation part of the first law of thermodynamics is the key to agriculture. Crop plants capture a little of the radiant energy from sunshine and use it with carbon dioxide from the air and with water and minerals from the soil to produce roots, leaves, stems, and fruits. In the process, part of the solar energy is converted to stored chemical energy in the organic compounds synthesized by the crop plants. Crops in turn provide the chemical energy that animals and humans require in their food. Investments of additional energy supplied by petroleum fossil fuel and electricity, along with other inputs (such as industrial fertilizer and pesticides) and use of appropriate mechanization make it possible to increase the productivity of the land and reduce the amount of human energy required to produce food and fibre (Chancellor and Goss, 1976; Hendrickson 1996; Timmer 1975). All of agriculture is based on this law whether producing food, fibre, fuel, crops, or livestock.

According to the second law of thermodynamic, the farm uses these energy inputs to reduce entropy, that is, prevent degradation of the cropland into disorder (Jordan, 2016). Without these energy inputs, successional species (weeds) would displace crop species (Schneider and Kay, 1994; Jordan, 2016). Money from the sale of yield provides feedback that stimulates further input of fuel, nitrogen, etc., and is a catalyst that maintains cropland as an improbable ecological community (Allen et al., 2003). If energy inputs are depleted more rapidly than they are replenished, the system disintegrates (Odum, 1995; Jordan, 2016). Production agriculture, both plant and animal, is in the business of maintaining order, fighting entropy to produce food,
fiber, and fuel. Agriculture is therefore in the energy and entropy business, a thermodynamic system indeed.

In a thermodynamic analysis of farming systems, input energy consists of direct solar energy (photosynthesis), indirect solar energy (rainfall), stored solar energy (soil organic matter), and energy inputs such as fertilizers, pesticides, and fuel that facilitate the conversion of solar energy to crop yield by maintaining structure of the cropland. Output energy is equivalent to the energy released by oxidation of the crop yield.

Implications of the Farm as a Thermodynamic System

Energy use in agriculture has become more intensive in response to increasing population, limited supply of arable land and a desire for higher living standards. In order to meet required food need of the growing population, chemical fertilizers, pesticides, farm tractors and machineries, electricity and other natural resources are used. This implies that the systems that produce the world's food supply are heavily dependent on fossil fuels. Vast amounts of these fuels are used as raw materials and energy in the manufacture of fertilisers and pesticides, and as available energy at all stages of food production: from planting, irrigation, weeding and harvesting, through to processing, distribution and packaging. In addition, fossil fuels are essential in the construction and the repair of equipment and infrastructure needed to facilitate this industry, including farm machinery, processing facilities, storage, trucks and roads.

This thermodynamic nature of agriculture has both positive and negative implications. Energy dependence of agriculture can lead to increase in the productivity of the land and reduction in the amount of human labour required to produce food and fibre. Energy, as a production input, is an essential element affecting the profitability and competitiveness of the agricultural sector. In addition, agriculture might become an important potential source of renewable energy and thus provide significant economic opportunities for farmers and the rural economy, as well as improving the environment.

On the other hand, agriculture also causes CO_2 emissions by using energy (e.g. fuel, electricity, heating) and is the final user of several inputs that are produced in an energy-intensive manner (e.g. fertilisers and pesticides). Emissions from on-farm energy use and production of fertilisers account for approximately 8 to 10% of global agricultural emissions (Sims et al., 2015; FAO, 2011; Wirsenius et al., 2011). One study concludes that in the absence of abatement measures, annual global emissions of GHG from agriculture are likely to increase by 30% by 2030 when compared to estimated levels in 2005 (McKinsey and Company, cited in Wreford et al., 2010). In addition, the continuing dependence on fossil fuels in the agricultural food sector creates a high risk of fluctuating prices, potentially making food somehow, temporarily unaffordable for the economically weak.

An important inference one can draw from the above contrasting implications is that the agricultural food sector must become more efficient to feed more people. This can be achieved either through energy efficiency measures or through the application of renewable energy. In any case, the entire agricultural value chain as shown in Fig. 2, will be involved in such changes. This includes: the input provider, the farmers, the processors, the engineers, the packagers, the distributors and retailers. Efficiency gains can be made in agricultural processing by decreasing energy input and use, as well as by reducing food losses before, during and after processing.

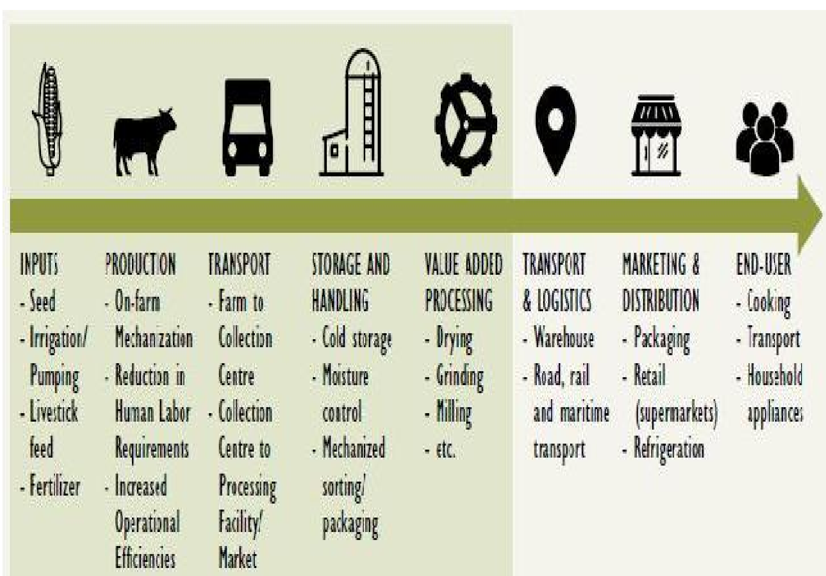


Fig. 2: Agricultural Value Chains (Sims et al., 2015)

From an energetic point of view, an efficient agricultural operation is defined as one in which the energy embodied in the outputs is higher than the inputs. However, the energy ratio (energy output/energy input) in agriculture has decreased from being close to 100 for traditional pre-industrial societies to less than 1 in most cases in the present food system, as energy inputs, mainly in the form of fossil fuels, have gradually increased (Church, 2005).

Mr. Vice-Chancellor Sir, it is worth mentioning that my chief research interests lie in this field of study, focusing on energy use and production in agriculture. I have been conducting research works on: (1) Energy analysis of crop production and cottage industrial process operations; (2) Thermo-catalytic and bio-conversion of wastes and biomass into useful industrial feedstock and energy; (3) Life cycle energetic studies of industrial equipment and facilities in selected production industries; (4) Design, construction, performance evaluation and maintenance of energy-saving cottage agricultural processing machines

My doctoral research thesis at the University of Ibadan and my postdoctoral work at Leibniz Institute of Agricultural Engineering, Potsdam, Germany formed part of these areas of specialization. All my subsequent research visits to Germany, Italy, USA, South Africa, UK, Poland, Czech Republic and Ethiopia have also been in further pursuit of these research interests.

It is also my passionate interest in these areas of research that prompted me to use keenly competitive conference grants won from Alexander von Humboldt Foundation, Germany (AvH) three times to organize international conferences where over 300 professors, policy makers, educationists and scholars were in attendance. Each of these conferences had a special edited book containing peer reviewed publications of contributors (Jekayinfa, 2012, 2013 and 2017). I have also been privileged to have received equipment and research grants and fellowships in these areas of research. These include DAAD fellowship, TWAS research grants, AvH research fellowship, AvH equipment and books grants, TETFUND book publication and research grants, International Centre for Theoretical Physics (ICTP)'s Conference Attendance Grant in Trieste, Italy, and others.

Mr. Vice-Chancellor Sir, the rest of this lecture therefore summarizes some of my contributions in the aforementioned research areas.

Energy Analysis of Agricultural Production Operations

One way to evaluate the sustainable development of agriculture is the use of energy flow method. This method, in an agricultural production system, refers to the energy consumed during production operations and energy saved when crops have been produced**.** Firstly, the amounts of inputs used in the production of a particular crop are specified in order to calculate the energy equivalences in the study. Energy input includes human labor, machinery, diesel fuel, chemical fertilizer, pesticides and seed amounts and output yield. Human energy expenditure is quantified by multiplying the number of persons engaged in an operation by the man-hour requirement and energy equivalent for human power. According to Odigboh (1998), at the maximum continuous energy consumption rate of 0.30 kW and conversion efficiency of 25%, the physical power output of a normal human being's labor in tropical climates is approximately 0.075 kW sustained for an 8–10 h workday.

Based on the energy equivalents of the inputs and output (Table 1), output–input energy ratio, energy productivity, specific energy and net energy gain can be calculated. This procedure was adopted for all the energy analyses carried out on various crops production. Typical energy analyses carried out on three crops (plantain, pineapple and mango) are being reported in this lecture. Others, not reported in this lecture, are soybean (Jekayinfa et al., 2013a) and wheat (Jekayinfa et al., 2015a and 2015b).

Energetics of Plantain Production

The total energy expenditure and energy output of plantain production in a group of plantain plantations of a research institute in Nigeria were estimated to be 7.60 GJ/ha and 16.32 GJ/ha respectively (Jekayinfa et al., 2012). The output/input energy ratio was 2.15. About 24% of energy used was generated by human labor, 41% from diesel oil and machinery, 28% from chemicals and fertilizers, while 7% of the total energy input was from other sources. Mean plantain yield was about 6000 kg/ha. The net energy and energy productivity value were estimated to be 8.72 GJ/ha and 0.79 kg/MJ, respectively. Plantain and banana constitute major food crops in Nigeria; as a result, large quantities of waste are often generated from the peels and have become a perennial problem in the cities. Indiscriminate disposal of these wastes when decomposed may produce noxious gases such as hydrogen sulphide, ammonia, etc. which could pose serious environmental hazards. Channeling these peels into the production of biofuels could serve as an efficient way for the management of the residues while the resulting gas could serve as a source of energy for cooking and lighting for the rural communities. Jekayinfa et al. (2012) further demonstrated that the energy potential of plantain residues (peels and trunks) is equivalent to energy of approximately 29 PJ or 0.69 million toe (tons of oil equivalent) of fuel-oil. There is therefore a very high potential of increasing the energy balance of plantain production if these residues are adequately harnessed either as biogas, ethyl alcohol, briquettes or for direct combustion.

Energetics of Pineapple Production

Direct input energy, indirect energy and other energy use indices in pineapples production in a group of pineapples plantations of a research farm in Nigeria were determined (Jekayinfa et al., 2013b). The economic indices of pineapples production and energy potentials of pineapples peelings were also estimated. Table 1 shows the inputs used in pineapples production in the area of survey and their energy equivalents with output energy rates and their equivalents. The total amount of energy used for various practices in the process of pineapples production was estimated to be 6.1 GJ /ha. The main sources of total energy used in the production process were diesel-oil (37.07%), human labour (46.02%), chemicals (18.05%), fertilisers (17.04%), and seeds (8.89%). In the surveyed farms, the average yield was 8,000 kg/ ha and the energy output-input ratio was 3.56 (Table 2). As summarised in Table 3, energy use in pineapple production is averagely efficient but could still be improved with reduction in energy inputs from cultural practices and a methodological shift from the use of energy from non-renewable sources to renewable ones. Other energy indices are shown in Table 4.

Possible energy contribution of Pineapple Peels (PP) in Nigerian situation was estimated as illustrated by the data in Table 5, calculated with the assumption that the selected crop residues are used within 10 km from its collection point. From data presented in Table 5, it can be inferred that for heat generation, 1 kg of PP can replace between 17.71 and 17.92 MJ by combustion of biogas from anaerobic digestion depending on the conventional technology replaced. For electricity generation, 1 kg of PP can replace 15.89 MJ (replacing grid electricity), 11.72 MJ (replacing diesel-fuelled electric-generating sets) and 17.53 MJ (replacing gasoline-fuelled electric-generating sets) by anaerobic digestion.

Table 1: Energy equivalents of different input and output values used in Pineapple production

Input	Energy equivalent (MJ/unit)	Reference
Human labour (h)	1.96	Singh and Singh (1992)
Machinery (h)	62.70	Singh and Singh (1992)
Chemical fertilizers (kg)		
Nitrogen	60.60	Singh and Singh (1992)
Phosphorus	11.10	Singh and Singh (1992)
Potassium	6.70	Singh and Singh (1992)
Farm yard manure (kg)	0.3	Singh and Singh (1992)
Chemicals (kg)		
Pesticides (general)	199	Singh et al. (2002)
Fungicides	92	Singh et al. (2002)
Herbicides	238	Singh et al. (2002)
Diesel-oil (l)	56.31	Singh and Singh (1992)
Electricity (kWh)	11.93	Singh and Singh (1992)
Water for irrigation (m3)	0.63	Yadav et al. (1991)
Output (kg)		
Pineapples	2.72	Collins (1960)

Source: Jekayinfa et al. (2013b)

Table 2: Energy consumption and energy input–output relationship for pineapples production

Input Quantity per unit area (ha)	Energy equivalent (MJ/unit)	Total energy equivalent (MJ)	Percentage of total energy input (%)
Human labour		**317.52**	**5.18**
Land preparation	1.96	98.00	1.60
Cultural practices	1.96	188.16	3.08
Harvesting	1.96	31.36	0.50
Machinery		**294.07**	**4.81**
Land preparation	62.70	73.36	1.20
Cultural practices	62.70	96.56	1.58
Transportation	62.70	124.15	2.03
Chemical fertilizer		**1042.72**	**17.04**
Nitrogen	60.60	805.98	13.17
Phosphorus	11.10	147.63	2.41
Potassium	6.70	89.11	1.46
Chemicals		**1104.00**	**18.05**
Pesticides (general)	199	398.00	6.51
Fungicides	92	230.00	0
Herbicides	238	476.00	7.78
Diesel-oil	56.31	**2815.50**	**46.02**
Pineapples sucker	2.72	**544.00**	**8.89**
Total energy input (MJ)		**6117.81**	**100**
Yield	2.72	**21760.00**	
Energy output–input ratio		**3.56**	

Source: Jekayinfa et al. (2013b)

Table 3: Energy input–output ratio in pineapples production

Items	Unit	Value
Energy input	MJ ha^{-1}	6117.81
Energy output	MJ ha^{-1}	21760.00
Pineapples yield	kg ha^{-1}	8000
Energy use efficiency	-	3.56
Specific energy	MJ kg^{-1}	0.75
Energy productivity	kg MJ^{-1}	1.31
Net energy	MJ ha^{-1}	15642.69

Source: Jekayinfa et al. (2013b)

Table 4: Total energy input in the form of direct, indirect, renewable and nonrenewable for pineapples production (MJ/ha).

Form of energy	Value (MJ ha^{-1})	% of total energy input
Direct energy[a]	3133.02	51.21
Indirect energy[b]	2984.79	48.79
Renewable energy[c]	861.52	14.08
Non-renewable energy[d]	5256.29	85.92
Total energy input	6117.81	

[a]Includes human labor, diesel [b]Includes seed, fertilizers, chemicals, machinery.
[c]Includes human labor,seed. [d]Includes diesel, chemical, fertilizers, machinery.

Source: Jekayinfa et al. (2013b)

Table 5: Energy returns of pineapples peels for various applications

Crop residue	Process	Output energy	Conventional technology replaced	Energy return (MJ/kg)
Pineapples peel	Anaerobic digestion	Heat	Oil-fired boiler	17.71
			Diesel oil-fired boiler	17.92
		Electricity	National grid	15.89
			Diesel genset	11.72
			Gasoline genset	17.53

Source: Jekayinfa et al. (2013b)

Energy Use in Mango Production

There is an estimated 3.7 million ha of mango worldwide (FAOSTAT, 2005). Mango production in 2004 was estimated at 26.6 million ton, ranked seventh in worldwide fruit production behind banana, grape, organs, apple, coconut and plantain. The top ten mango producing countries based on area of production include India, China, Thailand, Mexico, Indonesia, the Philippines, Nigeria, Pakistan, Guinea and Brazil (FAOSTAT, 2005; Yusuf and Salau, 2007). Fruits are available year round depending upon production location and cultivar. Jekayinfa et al. (2013c) investigated the direct input energy, indirect energy and other energy use indices in mango production in a group of mango plantation of a research farm in Nigeria. Energy potentials of mango by-products were also estimated. The average energy consumption for mango production was 15 GJ/ha. Out of the total energy, 93% was direct and 7% was indirect. Renewable energy accounted for 21% and energy usage efficiency was found to be 1.3. The total energy input into the production of 1 kg of mango was estimated to be 0.70 MJ. The dominant contribution to input was energy in the form of diesel used in tractor operation and captive power generation (56%), followed by human labor used for land preparation, cultural practices and harvesting (33%), machinery (5%) and chemicals, mainly herbicides (4%). The use of energetically available residues of mango could give an average value addition of 57 GJ/ha. As a result of benefit-cost ratio value (1.24), energy use efficiency and the energy value addition from mango residues, mango production was found to be economically efficient in the study area.

Energy Analysis in Crop and Animal Processing Operations

Few processing factories have any precise idea of the energy consumption of different production areas and in the absence of detailed internal monitoring, the energy efficiencies of different operations is also usually unknown. Knowledge of energy consumption for each product in a factory is useful for several purposes such as budgeting, evaluation of energy consumption for a given product, forecasting energy requirement in a plant, and for planning plant expansion.

In all the energy analyses of crop processing operations embarked upon, a method of energy accounting presented by Singh (1978) was used. The method involves the determination of the quantity of energy consumed at various locations within a processing plant. This particular information is needed before any sound energy conservation approaches may be attempted to reduce energy consumption in a crop and animal processing plant. The seven procedural steps involved in any energy accounting method are (Singh, 1978): determination of the objective, selection of a system boundary, charting a process flow diagram, identification of all mass and energy inputs, measurements of all mass and energy inputs, identification of all mass and energy outputs, and measurement or estimation of all mass and energy outputs. How many of these procedural steps will be involved in any energy accounting study depends on the set objective (Singh et al, 1997).

The energy accounting method has been used to account for energy use in various crop processing operations in Nigeria. Some of these studies are briefly summarized in this lecture. A Typical data collection at an oil mill during energy audit is shown in Plate 1.

Plate 1: Typical Data Collection in an Oil Mill during Energy Audit

Energy Use in Cassava-based Foods Production

The world's largest producer of cassava is Nigeria with a production of 57.14 million MT in 2016 (FAO, 2016). Flour or starch from roots and tubers, especially cassava are utilized in the preparation of various

food gels, snacks and baked goods. Such traditional products from cassava include gari, industrial starch, flour, etc.
Jekayinfa and Olajide (2007) carried out a study to investigate the energy use pattern in some selected cassava processing mills in southwestern Nigeria and develop predictive models that could estimate and optimize the energy demand of each unit operation for different selected cassava products (Cassava flour, Gari and Starch). The energy requirements of individual unit operations common in selected cassava processing plants for the different cassava products were determined. The principal operations involved in the production of each selected cassava-based food are highlighted in Fig. 3. The estimation of thermal energy (obtained from the use of fuel), electrical energy (obtained from electricity use from the national grid) and manual energy (from human labour) was done. The observed energy requirements per 1000 kg of fresh cassava tuber for production of gari, starch and flour were 327.17 MJ, 357.35 MJ and 345 MJ, respectively. The study identified the most energy-intensive operations in each production line and concluded from optimization results that the total minimum energy inputs required for the production of gari, cassava starch and cassava flour per tonne of fresh cassava tuber were 290.53, 305.20 and 315.60 MJ, respectively.

Using energy accounting symbols presented by Singh (1978) with slight modifications, energy and mass flow diagrams (Figs. 4 – 6) were constructed for a typical gari, starch and flour mills, respectively.

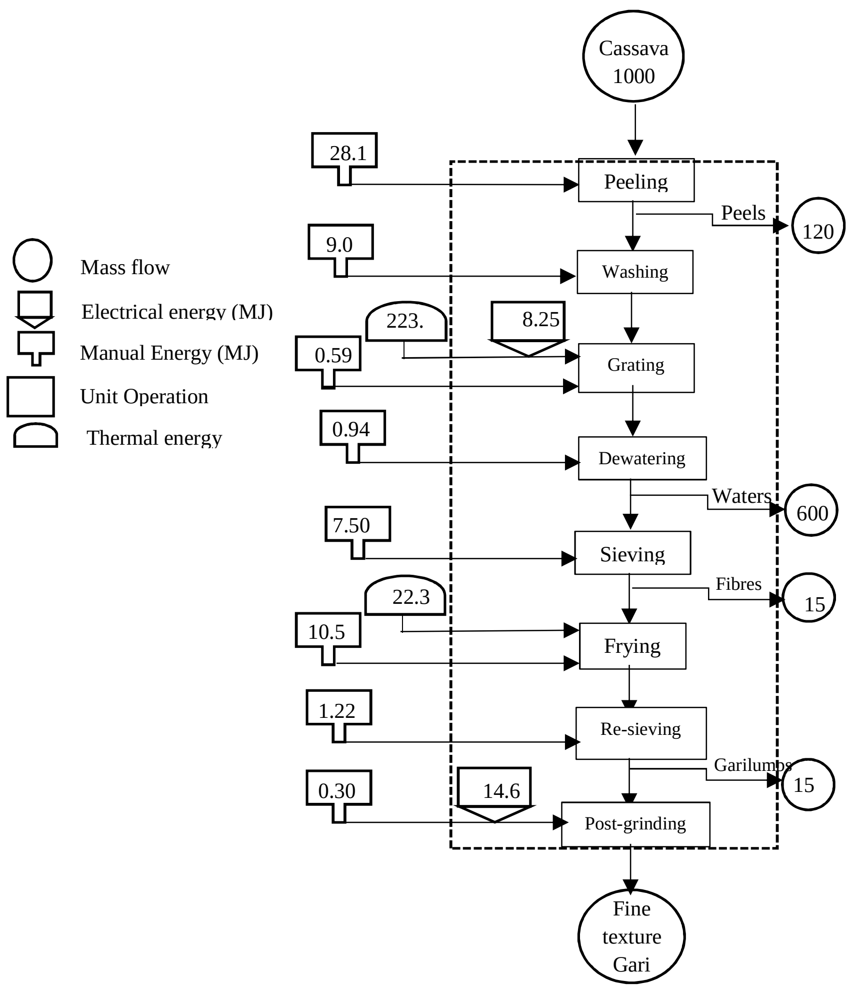
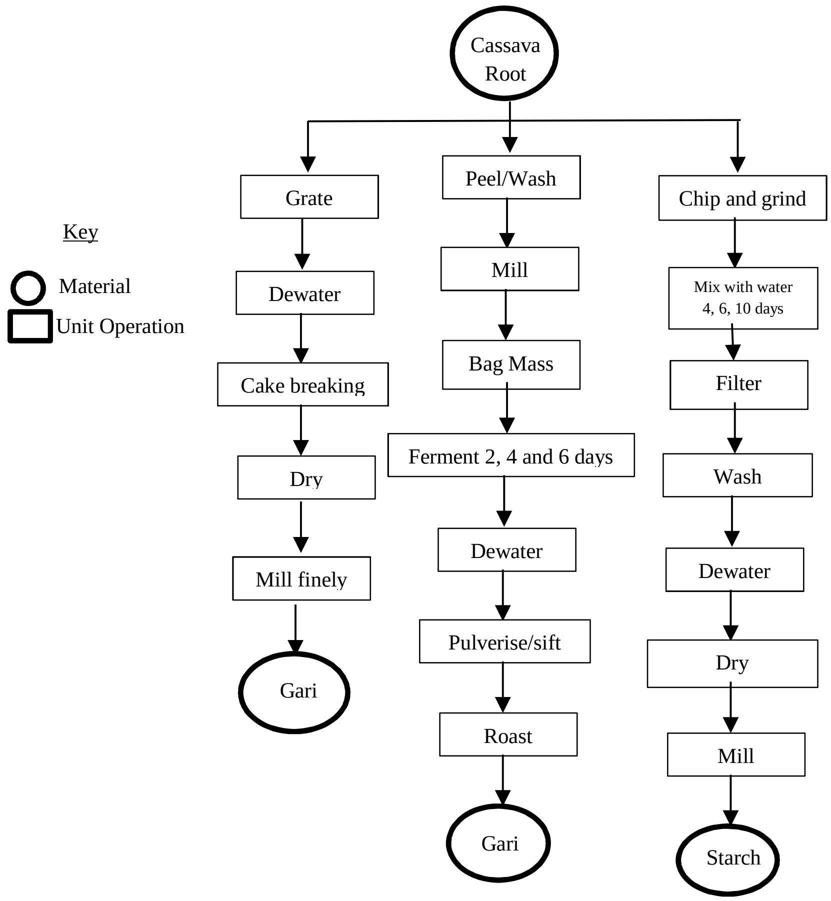


Fig. 3: Processing Steps for the Selected Cassava-based Products
Source: Jekayinfa and Olajide (2007)



: Energy Flow Diagram in Typical Gari Processing Mill.
Source: Jekayinfa and Olajide (2007)

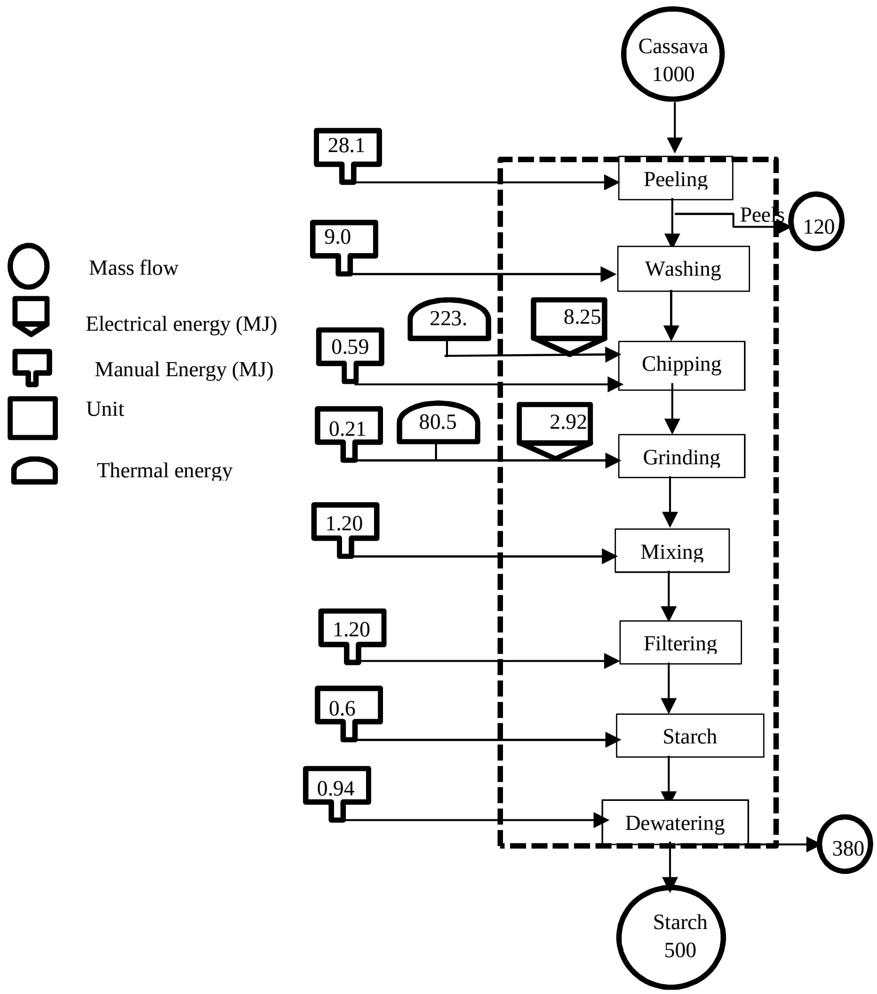


Fig.5: Energy Flow Diagram in Typical Starch Producing Mill.

Source: Jekayinfa and Olajide (2007)

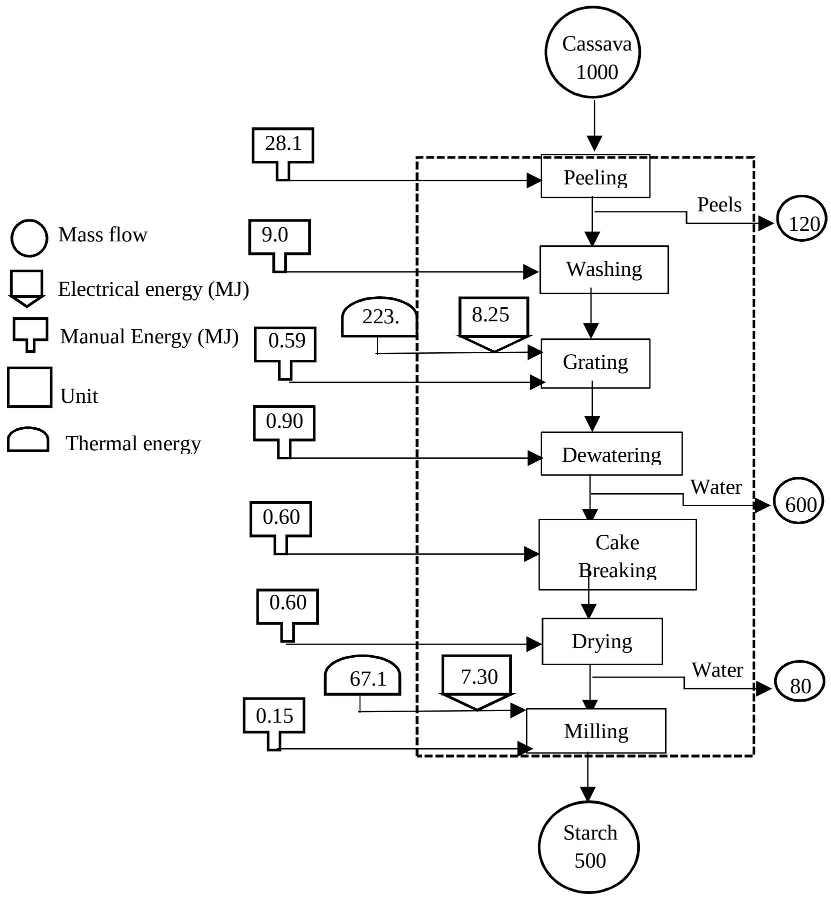


Fig. 6: Energy Flow Diagram in Typical Cassava Flour Producing Mill.
Source: Jekayinfa and Olajide (2007)

Equations (1), (2) and (3) are the optimization equations developed for gari, starch and cassava flour respectively from the raw energy data collected on the basis of different unit operations. The production output of different products under study was optimized by multi-variable technique with no constraints with respect to various energy inputs. The technique enables the maximum production output achieved and the optimum value of each unit operation to be calculated for each product.

$$Y_g = 25Pl_g + 8W_g + 1.3G_g + 2.5D_g + 20S_g + 20F_g + 3.2R_g + 2P_g \quad (1)$$

$$Y_s = 25Pl_s + 8W_s + 1.3C_s + 2.5GD_s + 20M_s + 20F_s + 3.25S_g + 2D_s \quad (2)$$

$$Y_f = 25Pl_f + 8W_f + 1.13G_f + 0.4D_f + 20C_f + ML_f \quad (3)$$

The terms are defined as follows:
Pl – peeling; W – washing; G – grating; D – dewatering; GD – grinding; C – chipping; S – sieving; F – frying; FG – filtering; R - re-sieving; P - post-grinding; M – mixing; SW - starch washing; ML – milling; DR – drying; CB - cake breaking; Y - production output of a particular cassava product; g – gari; s - cassava starch; f - cassava flour

Using the developed equations, the yield of each of the products was maximized, Gari yield was maximized for the optimum level of different energy inputs. The maximized yield value was estimated to be 325 kg of gari/tonne of cassava tuber for the total energy inputs level of 293.83 MJ. The maximized cassava starch output was estimated to be 585 kg/tonne of raw cassava tuber for the total energy inputs level of 305.20 MJ, while the maximized yield of cassava flour was 230 kg/ tonne of raw cassava tuber for 315.6 MJ of total energy input from all unit operations. The energy consumption for all manual operations in all selected production lines could be optimized by carefully deciding on the number of persons that could be involved in these operations on the basis of available work place thereby reducing time of operation, increasing production output and reducing unit cost of production. The energy use in mechanized operations could be optimized by using efficient and high-capacity processing machines.

In recent times life cycle assessment model (LCA) has been used to identify areas in production system that has tendency for reductions in the overall environmental impact. The usability of life cycle assessment as a powerful tool for process engineers to identify the most critical steps within the life cycle of a process has been established (Jekayinfa et al., 2013a). This allows the attention of engineers to be focused on those steps that create critical impact on the environment, which can be ameliorated by feasible technological alternatives. LCA has been successfully applied for cassava field production (Olaniran et al., 2016) and cassava flour production (Olaniran et al., 2017).

Energy Use in Cashew nut Processing

The cashew nut kernel is made up of three different portions—the shell, the kernel and the adhering testa. The primary product of cashew nuts is the kernel, which is the edible portion of the nut and is consumed in three ways: directly by the consumer; as roasted and salted nuts; and in confectionery and bakery products (Jekayinfa, 2008 and 2013). Cashew processing is a tedious and arduous task because of the irregular shape of the cashew nut, the presence of tough outer shell and the corrosive CNSL within the shell. The current sequence of cashew nut processing operations is outlined in Fig. 7. The processed kernels are either packaged for domestic retailing within the country or for export.

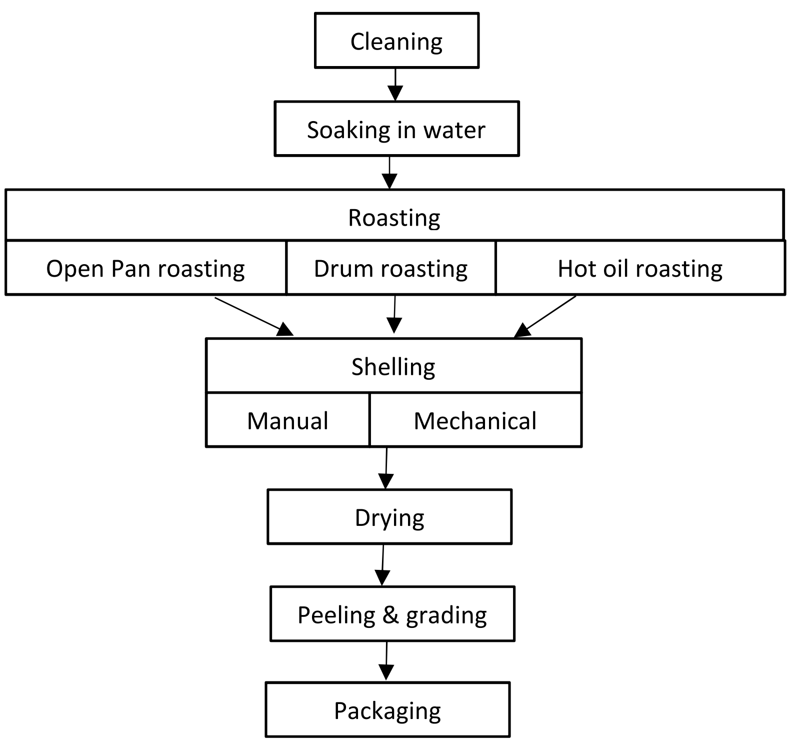


Fig. 7: Overview of Cashew Nut Processing
Source: Jekayinfa (2008)

Processing of cashew nut into cashew kernel locally has the potential to increase the incomes of producers, to create employment opportunity during harvesting and processing, and to increase export.

A study was carried out to estimate energy consumption in eight readily defined unit operations of cashew nut processing in Nigeria as outlined in Figure 7 (Jekayinfa and Bamgboye, 2003 and 2006). Data for analysis were collected from nine cashew nut mills stratified into small, medium and large categories to represent different mechanization levels. Analysis of data on total energy consumption by the cashew nut mills provides useful information on the energy sources available to them. From the three categories of cashew nut mills studied, it could be observed that some of the unit operations are energy-intensive, and an indication of the importance of energy utilization in the overall production system is exemplified by a typical time and energy-use data in Table 6 for a small mill.

The two identified energy intensive operations in cashew nut processing are cashew nut drying and cashew nut roasting, altogether accounting for over 85% of the total energy consumption in all the three mill categories.

Table 6: Time and Energy Use Data in Small-Scale Cashew Nut Processing Mill

Unit operation	Operation time (h)	Electrical energy (MJ)	Thermal energy (MJ)	Manual energy (MJ)	Total energy (MJ)	Percent of total
Cleaning	2.00	-	-	5.40	5.40	0.47
Soaking/ Conditional	3.00	-	-	8.10	8.10	0.70
Roasting	4.00	-	891.8	10.8	902.6	77.68
Shelling	4.50	28.80	-	7.29	36.09	3.11
Separation	4.00	-	-	6.48	6.48	0.56
Drying	3.50	-	172.1	5.83	177.93	15.31
Peeling and grading	5.80	-	-	23.43	23.43	2.02
Packaging	1.45	-	-	1.96	1.96	0.17
Total		**28.80**	**1063.9**	**69.29**	**1161.99**	
Percent of total		**2.48**	**91.56**	**5.96**		

Source: Jekayinfa (2008)

Energy and Exergy Analysis of Fruit Juice Processing

The need for adequate storage and processing, as well as for all year availability of fruits, has made fruit juice processing industry very important and on the forefront of various research works (Akdemir et al., 2002). Fruit juice processing involves operations such as sorting, sterilization, storage mechanism, refrigeration, extraction, mashing and evaporation. These operations require high and regular energy supply, thus an efficient energy system is needed.

Energy and exergy studies were conducted in an orange juice manufacturing industry in Nigeria to determine the energy consumption pattern and methods of energy optimization in the company (Waheed et al., 2008). An adaptation of the process analysis method of energy accounting was used to evaluate the energy requirement for each of the eight defined unit operations. The types of energy used in the manufacturing of orange juice were electrical, steam and manual amounting to 18.51%, 80.91% and 0.58% of the total energy respectively. It was estimated that an average energy intensity of 1.12 MJ/kg was required for the manufacturing of orange juice. The most energy intensive operation was identified as the pasteurizer followed by packaging unit with energy intensities of 0.932 and 0.119

MJ/kg, respectively. The exergy analysis (Table 7) revealed that the pasteurizer was responsible for most of the inefficiency (over 90%) followed by packaging (6.60%). It was suggested that the capacity of the pasteurizer be increased to reduce the level of inefficiency of the plant. The suggestion has been limited to equipment modification rather than process alteration, which constitutes additional investment cost and may not be economical from an energy savings perspective.

Table 7: Exergy Balance in an Orange Juice Processing Plant

Unit operation	Exergy change of the juice (MJ)	Useful work (MJ)	Utilities exergy change (MJ)	Production of entropy (MJ)	Inefficiency (%)
Sorting	-	5.40	-	5.40	0.03
Cleaning	-	67.13	-	67.13	0.32
Grating	-	90.20	-	90.20	0.44
Crusher	-	309.26	-	309.26	1.50
Screw finisher	-	90.20	-	90.20	0.44
Centrifuge/holding Tank	7.22	128.86	-	121.64	0.59
Pasteurizer	236.41	259.20	18,608.02	18,630.81	90.09
Packaging	-234.81	1130.11	-	1364.92	6.60
Total	**8.82**	**2080.36**	**18,608.02**	**20,679.56**	**100.00**

Source: Waheed et al. (2008)

Energy Use in Palm Kernel Oil Processing

Palm kernel oil (PKO) is a palm oil product that finds its usage in manufacture of artificial cream filings, soap, cosmetic and personal care products as well as emulsifiers in the food processing and pharmaceutical industry and the production of toiletries, tobacco, alkyd resins, paints and varnishes, cellophane, explosives and polyurethane (Jekayinfa and Bamgboye, 2004). Palm kernel cake (PKC) is another product from PKO extraction used as livestock feed.

As a result of these industrial uses of PKO, demands for PKO have been on the increase without any appreciable profit-margin to the producers owing to high input energy. Hence, the dwindling production of PKO in recent times. To be able to maintain an economically sustainable level of production of PKO, the industry will need to substantially reduce the cost of production, energy cost being a major component. PKO production as a whole consists of seven readily defined unit operations namely, palm-nut drying, palm-nut cracking, palm-kernel roasting, palm-kernel crushing, PKO expression, PKO sifting and PKO bottling/pumping in that order.

To quantify direct energy utilization in PKO processing, a study was conducted in nine palm-kernel oil (PKO) mills located in Southwestern Nigeria (Jekayinfa and Bamgboye, 2004, Bamgboye and Jekayinfa, 2006 and 2007). The mills were stratified into small, medium and large-scale categories, based on their modes of operations and production capacities. Evaluation of energy usage was carried out in the identified seven readily defined unit operations and PKO extraction rates in the three mill categories were evaluated. The average PKO extraction rate for small, medium and large mills were 48.45 percent, 42.68 percent and 36.24 percent, respectively. The total energy expenditure in small, medium and large-scale PKO mills were 350.89MJ/tonne, 230.70MJ/tonne and 181.74MJ/tonne, respectively. This suggests that the unit energy requirement for PKO output decreases as mill capacity increases. The four most highly energy-intensive operations identified were palm-nut cracking, palm-kernel roasting, palm kernel crushing and PKO expression, altogether accounting for 95.29, 92.14 and 93.65 percent of total energy used in small, medium and large-scale mills, respectively. Using modified energy accounting symbols presented by Singh (1978), an energy and mass flow diagram for a typical plant in small plant category was drawn as shown in Fig. 8. Electrical, fuel and human energy consumption are assigned to each functional unit.

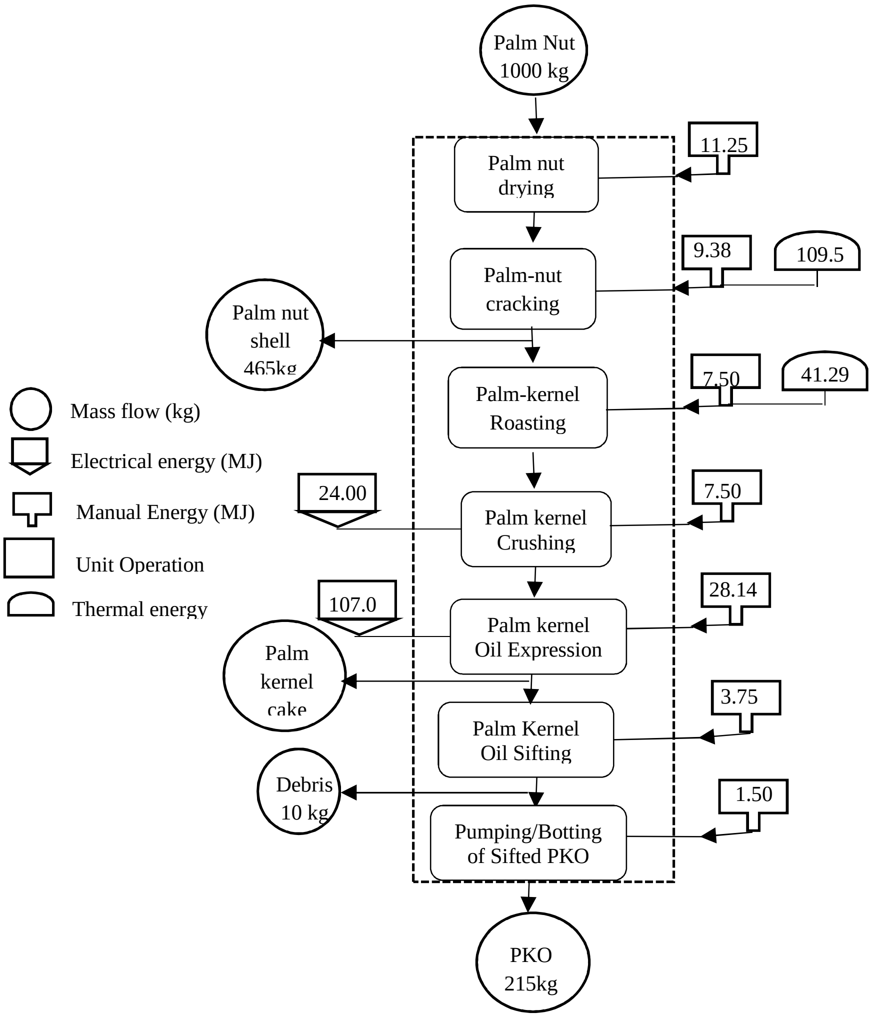


Fig. 8: Energy Flow Diagram in a Small PKO Mill
Source: Jekayinfa and Bamgboye (2004).

In a similar study, Jekayinfa and Bamgboye (2008) studied the energy use patterns and utilization efficiencies in 40 factories producing palm kernel oil (PKO) in southwestern part of Nigeria. The same stratification of the mills was done as in earlier study. In-situ data on petrol, diesel and electricity consumption and PKO production outputs for seven years (1998–2004) was collected from the factories. Energy use efficiency indicators employed include: energy intensity (EI), energy cost per unit product (EC/P), energy ratio (ER), food energy ratio (FER) and percentage oil yield by weight. Results of the study indicated that averagely, 0.58, 0.53 and 0.74 GJ/10^3 l of PKO were needed in the small, medium and large PKO factories, respectively. The average food energy ratios in the small, medium and large mills are 2.48, 2.53 and 2.14, respectively. The corresponding values of PKO conversion ratio are 0.43, 0.50 and 0.35. Electrical energy consumption in medium and large mills was lower than thermal energy due to irregularity and decline in electricity supply from the national grid.

Energy Use in Cocoa Processing

Energy consumption pattern of a cocoa processing plant which processed 6 tons of cocoa beans per day was studied. The plant has eight readily defined unit operations such as beans cleaning, micronizing and winnowing, roasting, grinding or milling, pressing of the cocoa liquor, filtering, tempering, and packaging.

The types of energy used in the manufacturing of cocoa products were electrical, thermal and manual energy, and the utilization of these for each unit operation was accounted for. The by-products resulting from cocoa processing were further chemically analysed to determine their suitability as domestic energy sources specifically for ethanol production. The results of the study indicated that the proportions of electrical and manual energy from the total energy consumption in the plant were 21995.67 and 6804 kWh respectively. The most highly energy intensive operations identified were drying of cocoa beans by micronizing machine, milling of the cocoa rubs, packaging of cocoa powder and cocoa butter and pressing of butter out of cocoa liquor altogether accounting for 7907.48kwh, 5892.29kwh, 3966.19kwh and 237.81 kWh respectively. The exergy analysis revealed that the pasteurizer was responsible for most of the inefficiency (over 90%) followed by packaging (6.60%). It was suggested that the capacity of the pasteurizer be increased to reduce the level of inefficiency of the plant.

Energy Use in Poultry Processing

Following the ban on the importation of poultry products by the Federal Government of Nigeria as policy measures to revive the economy and encourage the local poultry farmers, there has been an increase in the number of poultry processing plants in the country. A poultry processing plant is an integral part of an extensive poultry-farming venture comprising also the breeder flocks, hatchery, feed mill, broiler flocks and other related services. These areas of poultry business are mostly owned and controlled by a single organization. Poultry processing consists of five easily defined unit operations: slaughtering, scalding/defeathering, eviscerating, washing/chilling and packaging. All these process operations require energy in one form or the other, either as fossil fuel, electricity or human labour. Electricity is used for refrigeration, lighting, air conditioning and other mechanical drives. Fossil fuels are used for production of hot water for defeathering operation.

Energy audit of three poultry processing plants was conducted in southwestern Nigeria (Jekayinfa, 2007). The plants were grouped into three different categories based on their production capacities. The results of the audit revealed that scalding/defeathering is the most energy intensive unit operation in all the three plant categories, averagely accounting for about 44% of the total energy consumption in the processing plants. Other processing operations consuming energy in the following order are eviscerating (17.5%), slaughtering (17%), washing & chilling (16%) and packing (6%).

Energy Analysis of Thin Layer Drying of Physic Nut (Jatropha Curcas)

The Nigerian Biofuel Policy and Incentives (NNPC, 2007) qualifies crops such as cassava, sugarcane, oil palm, jatropha, cellulose-based materials and any other crop as may be approved by the Biofuel Energy Commission as feedstock for biofuel production in Nigeria. Physic nut (*Jatropha curcas*) is considered to be one of the promising energy crops (JWT, 2010) in which its seeds contain 27-40 % oil and average of 34.4% (Achten et al., 2008). Although it produces lower yields of oil than oil palm, it has been reported that physic nut has several advantages including being able to grow on poor land (arid and marginal land), improving soil quality, requiring small amount of water, fertilizer and pesticides and providing several by-products from the production of jatropha biodiesel such as wood, fertilizer and glycerin (Prueksachat and Shabbir, 2006).

A comprehensive study of energy efficiency of physic nuts dried at different temperatures and varying air velocities for biodiesel production is required, before starting a large–scale production. Onifade and Jekayinfa (2015) carried out the energy analysis of thin layer drying of physic nut by fitting data obtained from the drying kinetics into energy equations to obtain the energy utilization (EU), energy utilization ratio (EUR) and heat transfer rate due to evaporation (Q_{evap}). EU and EUR increased as temperature and air velocity increased, but Q_{evap} decreased with increased drying conditions. Hence, heat energy supplied by the crop dryer was utilized to produce high quality products. The optimum value of EU was 5.468 J/s at 80 ^{o}C and 5.0 m/s while that of EUR was 0.85 obtained at a drying air of 80 ^{o}C at air velocity of 1.0 m/s. Maximum and minimum values of Q_{evap} were 17.1 J/s and 3.979 J/s while drying at 80 and 40 ^{o}C and at air velocity of 1.0 and 5.0 m/s respectively. It can be concluded that energy was maximally utilized in the drying process of the physic nuts and the dried products obtained can be recommended for further processing (for bio-oil and biofuel production).

Life Cycle Energetic Analysis of Process Equipment

There is a growing paradigm on a large-scale in several developed countries on the need to consciously ensure that industrial products and social infrastructures and services are developed for efficient energy utilisation and environmental sustainability. On the contrary, little effort is made in many developing countries such as Nigeria to determine the ecological impact and cost of using old conventional technologies such as steam boilers, refrigeration plants, etc. Hence it is very imperative to study the implications of the continuous use of these old technologies especially as it relates to the use of different sources of fuel, economy, and ecological impacts. One of such old conventional technologies of concern is the steam boiler.

Energetic Study of Industrial Steam Boilers

Steam boilers remain inevitably important in several industrial, domestic and manufacturing applications for heating, processing and power generation, amongst others. A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam (UNEP, 2010). Steam production is basically an energy conversion process in which fuel energy is converted into energy resident in steam. Several factors are key ingredients in boiler performance. A steam system analysis investigates the energy transfer of the fuel to the steam and the steam to other processes (Harrell, 2002).

The cumulative energy and exergy assessment of Low Pour Fuel Oil (LPFO)-operated steam boilers was carried out by Ohijeagbon et al. (2012a and 2013a). The energy resource utilisation of LPFO in the combustion and heat exchanging units of industrial steam boilers was investigated by considering both the physical and chemical exergies of the material streams in boiler operations used in Nigeria. The chemical exergies of LPFO and the exhaust flue gases were 44,566.66 and 147.97 kJ/kg, respectively, for LPFO undergoing complete combustion process. Higher evaporation ratios and energy consumption by steam were associated with reduction in heat loss. Lower exergy destruction was due to lower rapid changes in temperature potential for the generation of steam in the heat exchanging unit. The average energy and exergy efficiencies of the boilers were obtained as 69.54 and 38.5%, respectively. The exergy efficiencies obtained for the combustion and heat exchanging units for the boilers investigated were 55.35, 49.06 and 58.69 and 63.80%, respectively. The results of this study are very useful for energy resources management and control of oil-fired industrial steam boilers. In the course of conducting this research work, a framework was also developed to evaluate thermodynamic properties and performance variables associated with material streams in steam boilers (Ohijeagbon, et al., 2013b and 2015). The framework offers advanced thermodynamic solutions based on first principles to determine mass flow rate, temperatures, enthalpies and entropies which could be used to obtain performance indices, resources allocation, areas and magnitude of energy losses and exergy destruction. Instructors, researchers and advanced students of engineering, sciences and energy analysis are expected to find this material as a helpful tool to quickly understand fundamental concepts and approach required in energy and exergy analysis of industrial plants.

In another similar study, the emissions analysis of industrial steam boilers using low pour fuel oil (LPFO) and diesel fuels was conducted in order to reveal their ecological impacts and sustainability (Ohijeagbon et al., 2012b). The results of this particular study show that the levels of uncontrolled boiler emissions on the environment can lead to increased greenhouse effects, global warming, and pollution and toxilogical impacts on human health. Only carbon monoxide emission was found to vary with the levels of oxygen generation in the products of combustion, while other substances were generally in relation to constituents and rates of consumption of fuel. Reduction in exergetic losses and subsequently gain in energy savings can be achieved in steam boilers by maintaining the input fuel value and increasing the evaporation ratio of steam boiler operation (Ohijeagbon et al., 2014) .

Embodied Energy in Agricultural Buildings and Machineries

The embodied energy of an entire building, or an item, or a basic material in a building, comprises direct and indirect energy. Indirect energy is used to create the inputs of goods and services to the main process, whereas direct energy is that used directly for the main process, whether it is the construction of the building, product assembly, or material manufacture. The material intensities have been evaluated by the study of a number of similar components on houses of various sizes to find relationships between quantity and area (Pullen, 2000). If the quantity of a material is multiplied by its embodied energy coefficient, then the energy used to produce that material in the house can be calculated. The total embodied energy for all the materials can then be found by summing the individual values (Pullen, 2000).

A study was undertaken to estimate the total energy embodied in a typical mechanized farm in Nigeria (Jekayinfa et al., 2015c). Eight (8) different farm structures (maintenance and storage shed, feed mill, farm office, piggery, poultry and hatchery, farm quarters, silo and storage cribs) which are critical on the farm were selected for analysis. Different components and quantities of materials required for each structure were collected from their Architectural design and their various masses and their corresponding energy equivalent were determined. The total embodied energy (EE) required by the farm was estimated to be 5,044.49 GJ with the corresponding embodied energy values for the maintenance and storage shed, feed mill, farm office, piggery, poultry and hatchery, farm quarters, silo and storage crib being estimated as 539.74 GJ, 1817.01 GJ, 672.36 GJ, 264.19 GJ, 813.63 GJ, 913.3 GJ, 21.93 GJ, and 2.33 GJ respectively (Table 8). This clearly indicated that feed mill, poultry and hatchery, and farm quarters have higher energy consumption, and thereby emitted greater greenhouse gases which escalate global warming tendency.

Table 8: Summary of Calculated Embodied Energy

Structure	**IEE (GJ)**	**DEE (GJ)**	**REE (GJ)**	**TEE (GJ)**
Maintenance & Storage Shed	410.20	48.58	80.96	539.74
Feed mill	1,380.93	272.55	163.53	1,817.01
Farm office	511	100.85	60.51	672.36
Piggery	200.78	39.63	23.78	264.19
Poultry & Hatchery	618.36	122.04	63.23	813.63
Farm Quarter	697.91	137.75	82.65	913.30
Silo	16.67	3.29	1.97	21.93
Storage Crib	1.77	0.35	0.21	2.33
Total	3,837.62	725.04	476.84	5,044.49

Keyword: IEE (Indirect Embodied Energy), DEE (Direct Embodied Energy), REE (Recurring Embodied Energy), TEE (Total Embodied Energy)

Source: Jekayinfa et al. (2015c)

Availability and Energy Potentials of Agricultural Residues

Potential Availability of Energetically Usable Crop Residues in Nigeria

Agriculture is an important part of the economy in Nigeria. Besides the crop itself, large quantities of residues are generated every year (Jekayinfa and Scholz, 2007a). The term agricultural residue is used to describe all the organic materials which are produced as the by-products from agricultural activities. These residues constitute a major part of the total annual production of biomass residues and are an important source of energy both for domestic as well as industrial purposes. Agricultural residues could be divided into field-based residues and process-based residues. The biomass materials, which are generated on the agricultural farm or field are defined as field-based residues (e.g. rice straw, sugar cane tops, cocoa pods, tobacco stalks, soybean straw/pods, maize stalks, etc.). Whereas those generated during processing of agricultural products are called process-based residues (e.g. rice husk, bagasse, maize cob/husk, coffee husk, peanuts shell, etc.). Such classification is important, especially under the context of energy application, as the availability of and accessibility to these sources critically depend on this attribute. Availability of field-based residues for energy application is usually limited since collection for utilization is difficult and there are other alternative uses such as for fertilizing and animal feed.

Assessment of available agricultural residues is helpful in revealing its status and helps in taking conservation measures and ensures a sustained supply to meet the energy demand. The knowledge of residue resources and their availability is also essential before a detailed evaluation of present consumption patterns and feasibility of introducing modern biomass fuel-based applications is carried out. Literature is replete with many attempts to estimate global and national production and use of residues, but with large variations. These include residues availability in the Philippines (Elauria et al., 2005), India (Reddy, 1994), Karnataka (Ramachandra et al., 2004), and selected Asian countries (Bhattacharya et al., 1999, 2005). An assessment of the potential availability of selected residues from maize, cassava, millet, plantain, groundnuts, sorghum, oil palm, palm kernel, and cowpeas for possible conversion to renewable energy in Nigeria was done (Jekayinfa and Scholz, 2009). As shown in Table 9, it is estimated that nearly 58 million tonnes of these residues were potentially available in the year 2004 with energy potential of about 20.8 million tonnes oil equivalents. The residue availability for 2010 is projected to be about 80 million tonnes. These residues, when converted to energetically usable forms, can substitute or complement the fossil energy sources in Nigeria by more than 80% (Jekayinfa and Scholz, 2009).

Energy Potentials of Some Agricultural Residues as Local Fuel Materials

Many elementary properties of biomass have been determined for a wide range of fuel types (Jekayinfa and Omisakin, 2015). These properties include physical size and shape, elemental composition (ultimate analysis), moisture content, heating value, bulk density, specific gravity, thermal conductivity, and mechanical, acoustic, and electrical properties. Proximate analysis is the standard test method for evaluating solid fuels, which classifies the raw material in terms of moisture, volatile matter, ash and fixed carbon contents. Proximate analysis can also be presented on dry basis, i.e. in terms of volatile matter, fixed carbon and ash. Ultimate analysis of biomass shows its composition in terms of ash and chemical elements such as carbon, hydrogen, nitrogen, sulfur and oxygen. The standard measure of the energy content of a fuel is its heating value, sometimes called calorific value or heat of combustion. Heating value of biomass depends on its composition (Turkenburg, 2000). Dry woody biomass consists of cellulose, hemicelluloses, lignin and ash. Its heating value can therefore be estimated from the heating value and weight fraction of each constituent.

Table 9: Estimated amounts of agricultural residues generated in Nigeria in 2004

Major crop	Crop yield (10^6 t)	Type of residue	RPR*	Residue amount (10^6 t)
Maize	4.78	Cob	0.273	1.30
		Stalk	2.000	9.56
		Husk	0.200	0.96
Cassava	38.18	Stalks	0.062	2.37
		Peelings	0.250	9.54
Millet	6.28	Stalks	1.750	11.00
Plantain	2.42	Peels	0.40	8.44
		Trunks/leaves	0.50	1.05
Groundnuts	2.94	Husks/shells	0.477	1.40
		Straw	2.300	6.76
Sorghum	8.03	Straw	1.750	14.05
Oil palm	4.78	Shell	0.065	0.31
		Fibre	0.140	0.67
		Empty bunches	0.230	1.10
Palm kernel	8.70	Shells	0.45	3.92
		Cake	0.25	2.18
Cowpea	2.32	Shells	1.75	4.05
Total				**69.56**

Data for crop production available from FAO statistics (see http://www.fao.org).
*Residue to Product Ratio
Source: Jekayinfa and Scholz (2009)

Jekayinfa and Omisakin (2005) subjected ten agricultural residues in Nigeria to ultimate and proximate analyses to determine their energy content using the method of Association of Official Analytical Chemists. The samples are: groundnut shell, yam peels, coconut shell, mango peels, palm oil mill effluents, corn cob, cherry, orange peels, melon shell, and black walnut hull. The results obtained for ultimate and proximate analyses are presented in Table 10 and Table 11 respectively. Table 12 presents the combustion characteristics of the waste samples.

Results of analysis show that the mean higher heating values of the residue samples are 16505kJ/kg, 19597kJ/kg, 20647kJ/kg, 15891kJ/kg, 17303kJ/kg, 19458kJ/kg, 28203kJ/kg, 19299kJ/kg, 21392kJ/kg and 21143kJ/kg for groundnut shell, yam peels, coconut shell, mango peels, palm oil mill effluent, corn cob, cherry, orange peels, melon shell and black walnut hull respectively. All the residue samples considered have heat values greater than some well-known biomass-fuels and fall within the limit for the production of steam in electricity generation. As a result of this, it is envisaged that industries that use their waste biomass for energy would simultaneously solve a waste disposal problem and save money on their energy needs.

Table 10: Ultimate Composition of the Selected Agricultural Residues

	Parameters				
Residues	**% Carbon**	**% Hydrogen**	**% Nitrogen**	**% Oxygen**	**% Sulphur**
Groundnut shell	14.99	16.42	1.21	63.62	3.00
Yam peels	25.35	13.54	2.67	49.60	4.34
Coconut shell	20.68	16.26	1.14	54.49	3.96
Mango peels	19.83	13.19	2.40	55.39	4.86
Palm oil mill effluent	12.74	16.49	0.41	58.33	1.06
Corn cob	19.73	15.56	0.38	54.98	4.48
Cherry	19.54	21.19	0.65	51.13	3.69
Orange peels	16.23	17.10	0.76	60.26	2.99
Melon shell	21.61	14.71	0.26	39.03	4.82
Black walnut hull	23.09	15.66	0.94	52.25	3.96

Source: Jekayinfa and Omisakin (2005)

Table 11: Proximate Composition of the Selected Agricultural Residues

Residues			%		
	Dry matter	**Fixed Carbon**	**Crude protein**	**Crude fiber**	**Ether extract**
Groundnut shell	70.50	15.50	5.23	5.35	3.42
Yam peels	73.75	14.50	3.62	2.51	5.62
Coconut shell	71.51	8.78	6.53	10.35	2.83
Mango peels	75.25	9.57	3.51	8.58	3.09
Palm oil mill effluent	70.51	10.52	7.21	8.12	3.64
Corn cob	65.25	8.75	6.25	16.50	3.25
Cherry	46.50	23.50	7.75	16.95	5.30
Orange peels	45.65	25.51	6.95	14.23	7.66
Melon shell	60.55	21.53	4.15	10.25	3.52
Black walnut hull	71.25	13.91	4.65	6.53	3.66

Source: Jekayinfa and Omisakin (2005)

Table 12: Combustion Characteristics of the Ten Selected Agricultural Processing Residues

Residues	**Heat contents (kJ/kg)**		**Ash (%)**	**Moisture content (as received, wet basis) (%)**
	Higher	**Lower**		
Groundnut shell	17428	13785	0.76	8.76
Yam peels	19437	16433	4.50	64.50
Coconut shell	20838	17231	3.47	12.22
Mango peels	16093	13167	4.33	56.54
Palm oil mill effluent	17530	13872	10.97	7.52
Corn cob	19480	16028	4.87	42.98
Cherry	28068	23367	3.80	37.75
Orange peels	19416	15622	2.66	10.82
Melon shell	21779	18516	19.57	27.60
Black walnut hull	21193	17719	4.10	11.56

Source: Jekayinfa and Omisakin (2005)

Estimation of possible energy contributions of crop residues in Nigeria

The use of agricultural wastes as energy has many unique qualities that provide environmental benefits. It helps to mitigate climate change, reduces acid rain, soil erosion, water pollution and pressure on landfills. It also provides wildlife habitat, and helps to maintain forest health through better management.

Jekayinfa and Scholz (2007b and 2013a) estimated the potential energy contribution of some selected crop residues in Nigeria by calculating their net heat values, after merely accounting for process conversion efficiency. The approach used by Pellizzi (1986) while reporting a procedure for estimating energy contribution of biomass using Italy as a case study was used in this study. The procedure adopted involves the energy costs upstream of the envisaged crop residues conversion plant, the efficiency of the commercial plant to be substituted, the value of process effluents or by-products and the replacement energy cost of conventional energy. These factors are, however, also relevant in evaluating the economic advantages offered by renewable against conventional energy. Using this methodology, energy content, replacement energy value, energy cost and energy return of crop residue (kJ per kg dry matter) were considered. The cost estimates of these residues using 2008 crops production data vary from US$6.45/tonne to US$23.12/tonne, depending on the type of crop residue and the transportation distance. Estimation of values of energy from maize stover, cassava peels, millet stover and sorghum straw showed that about 30 million tonnes are energetically available in Nigeria in 2010 and could replace 1.05 PJ/year if they were used exclusively for heat generation by direct combustion, or 0.58 PJ/year if used in gasification processes to generate electricity and replace the energy currently supplied from the national grid.

Crop Residues Conversion Technologies and Products

The most common simplest and cheapest method of converting raw biomass to energy is by direct combustion However because of the bulky nature of raw biomass, using it directly is not convenient and economical. Therefore, before bioenergy is used for end-use activities, it may have to be converted from its primary form into a secondary form that is more convenient for transport and use (Turkenburg, 2000). This may involve simple physical processing before combustion or upgrading to a variety of convenient secondary fuels (in solid, liquid or gas form) by means of certain conversion processes. Fig. 9 shows the methods of utilizing biomass as a source of energy (Turkenburg, 2000).

Biomass Densification

Raw biomass has low energy density, is hygroscopic and rots during storage. The bulky nature of raw biomass makes storage and transport uneconomical (Lipinsky et al., 2002). Studies on biomass gasification have also shown that fluffy or low density biomass performed poorly (Ojolo and Orisaleye, 2010). Poor biomass properties have, therefore limited the full utilization of the huge potential of biomass which is particularly abundant in rural areas of developing countries which are basically agro-based (Jekayinfa and Scholz, 2009). Hence, there is a need to mechanically transform biomass materials into forms which will have better properties such as higher bulk density, higher energy density and hydrophobicity. This is done by compaction or densification. Biomass densification is a process of producing solid biofuel by reducing the bulk volume of the material by mechanical means for easy handling, transportation and storage (Rosillo-Calle et al., 2007). The existing technologies for biomass densification include the screw press, piston press, roller press and pelleting technologies. Each of the technologies have their merits and demerits and it has been acknowledged that there is considerable scope for the design improvements which will lead to extended life of wearing parts and reduce energy consumption (Chen et al., 2009).

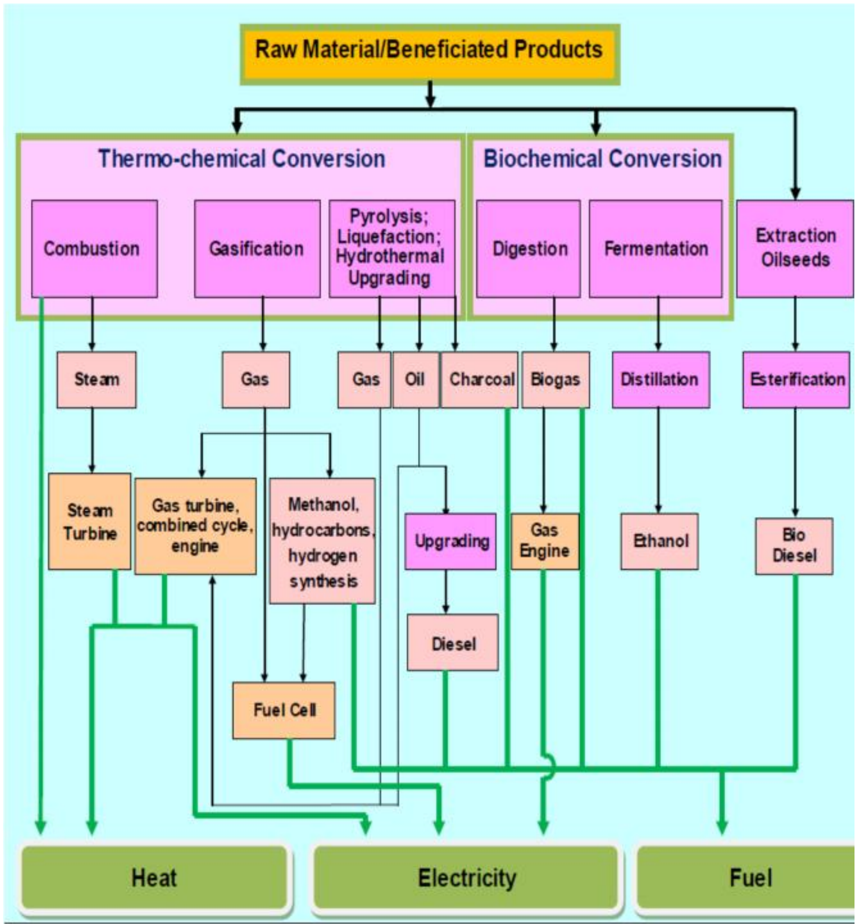


Fig. 9: Methods of Utilizing Biomass as a Source of Energy
***Source*:** Turkenburg, (2000).

A laboratory uniaxial press (Fig.10) was developed for the production of biomass briquettes under controlled conditions with a maximum pressure of 25 MPa (Jekayinfa and Orisaleye, 2018). A size reduction machine for biomass materials was also designed to process maize stover and maize cobs into smaller particles (Jekayinfa et al., 2012). For maize stover, the process is a two-staged process which involves chopping of the stalk followed by milling while maize cobs are fed directly to the hammer mill. A thermochemical reactor was designed for torrefaction of the biomass materials. Performance evaluation of the laboratory press was carried out using untreated maize cobs as material and a full factorial experimental design was employed. Process variables investigated were the pressure, temperature and hold time and the material variable investigated was the particle size. Briquettes were produced using the developed press with pressures ranging between 9 and 15 MPa. Temperatures used were 90°C and 120°C while hold times used were 7.5 minutes and 15 minutes. Particles were sieved into sizes greater than 2.5 mm and sizes less than 2.5 mm. The density of corn cob briquettes produced under these conditions ranged from 570 kg/m^3 and 1300 kg/m^3.

It was observed from graphical analysis that the pressure, temperature and particle size influenced the density of the corn cob briquettes whilst the hold time did not show a definite pattern for its effect on the briquettes density. Statistical analysis showed that the pressure, temperature and particle size had statistically significant effects on the density off the briquettes. Also, the effect of the interaction between the temperature and particle size of the milled corn cob particles was also statistically significant. The findings give insight on how the densification variables affect density of corn cob briquettes.

Thermochemical Conversion

Processes in the thermochemical conversion of biomass to energy include pyrolysis (carbonization, destructive distillation & fast pyrolysis), gasification or liquefaction. Out of these processes, pyrolysis is the basic thermochemical process to convert biomass into more valuable or more convenient products. Conventional pyrolysis involves heating the original material in the near-absence of air, typically at 300 - 500°C, until the volatile matters has been driven off.

Pyrolysis of sandbox shell was carried out with the aim of investigating the effect of pyrolysis parameters on the pyrolysis process and identifying production conditions for the yield of biochar (Ola and Jekayinfa, 2014a). Parameters investigated were heating temperature (400, 500 and 600°C), heating time (10, 20, and 30 min) and particle size of feedstock (0–1.0, 1.0–2.5 and 2.5–5.0 mm) in a laboratory batch pyrolysis process. The experiment was designed by applying response surface methodology through a three-factor full factorial design.

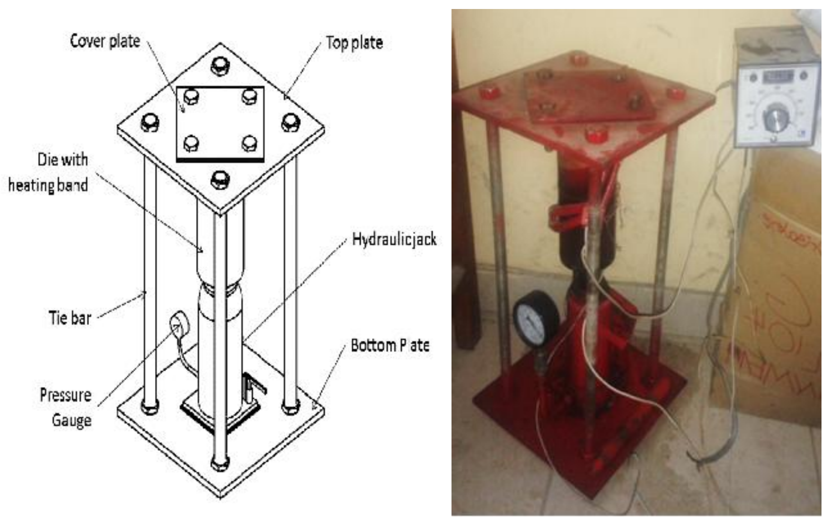


Fig.10: The developed experimental biomass briquetting Press
Source: Jekayinfa and Orisaleye (2018)

All the three variables significantly affected the biochar yield from sandbox shell, with heating temperature being the most effective followed by heating time and particle size of feedstock. Maximum biochar yield of 39.65% wt. occurred at 400°C heating temperature and 10 min heating time with 1.0–2.5 mm particle size. The fuel properties of the raw sandbox shell and the solid biochar obtained were characterized (Ola and Jekayinfa, 2015). The biochar exhibited a higher carbon and lower hydrogen, oxygen and nitrogen contents than the original feedstock. The sandbox shell and biochar had heating values of 23.51 and 25.92 MJ/kg respectively. Using the same pyrolysis batch process and reactor, the optimum process conditions for the pyrolysis product yields from mango stone shell were determined with a two factor hexagonal factorial design in response surface methodology (Ola and Jekayinfa, 2014b). Maximum yields with the accompanying optimal conditions of biochar, pyrolytic oil and biogas obtained were 16.68 wt% (at 300 ºC and 20 min), 11.03 wt% (at 500 ºC and 20 min) and 7.36 wt% (at 400 ºC and 20 min), respectively. The raw mango stone shell had heating value, nitrogen, ash, and fixed carbon contents of 21.74 MJ/kg, 0.35, 1.89, 18.4 wt%, respectively. The bio-oil obtained compared favorably with the ASTM D6751-02, EU EN14214 standards for biodiesel and No 6 fuel.

In another study conducted by Onifade et al. (2017), lignocellulosic materials obtained from two agricultural residues through renewable technology were used to produce bio-energy and chemical feedstock. The lignocellulosic materials were extracted from palm fruit (*Elaeis guineensis*) fibre and physic nut (*Jatropha curcas*) shell, and pyrolyzed under low temperature and pressure at various particle sizes. The main properties of solid (lignocellulosic) materials were tested and the bio-oil produced was analyzed using GC-MS. Results show proximate analyses (volatile, ash and fixed carbon contents) and ultimate analysis (carbon, oxygen, nitrogen, magnesium, phosphorus and zinc). The pH value of the bio-oil from both residues increased with increase in temperatures. The density, viscosity and calorific value of the palm and physic residue oil are 831.99 and 947.5 kg/m3, 0.695 and 1.58 cPa at room temperature, 22.33 and 14.169 kJ/g, respectively. Aromatics and other compounds are major dominant compounds in the palm fruit fibre oil which is characterized for bio-fuel production. Physic nut shell oil contains aromatic ethers, cyclic ethers, secondary amides and organic halogen compound which are important chemical feedstock.

Anaerobic Digestion Process

Anaerobic digestion is a complex biochemical process carried out in a number of steps by several types of microorganisms in the absence of oxygen. Methane and carbon dioxide are the principal end products, with minor quantities of nitrogen, hydrogen, ammonia and hydrogen sulphide. The breaking down of biodegradable materials in the absence of oxygen produces biogas suitable for energy conversion (Vindis *et al.,* 2009). Anaerobic digestion takes place in four phases: hydrolysis/ liquefaction, acidogenesis, acetogenesis and methanogenesis. Biogas generally composes of methane, CH_4, (50-75%), carbon dioxide, CO_2 (20-40%), nitrogen, N_2 (1-2%), hydrogen, H_2 (5-10%), and hydrogen sulphide H_2S (0- 1%) (Navickas., 2007, Swedish Gas Centre, 2010). Anaerobic digestion of the large quantities of agricultural solid waste can provide biogas as well as other benefits such as reduction in waste volume, the production of bio-fertiliser and valuable soil conditioners (Grommen and Verstraete, 2002).

The feasibility of utilizing cassava tuber, cassava peels, palm kernel cake, and palm kernel shells in methane production through anaerobic digestion was evaluated by Jekayinfa and Scholz (2013b). This was done at a laboratory scale using the simple single-state digesters of 2 litre working volume. The digester was fed on a batch-basis with the slurry of each of these feedstocks containing average moisture content of 18% and operated at a temperature of 35ºC for 30 days. Measured biogas yields for cassava tuber, cassava peels, palm kernel cake, and palm kernel shell were 0.66, 0.66, 0.58, and 0.08 m^3/ (kg VS), respectively, after 30 days digestion time. Similarly, methane production was 0.31, 0.28, 0.32, and 0.05 m3/ (kg VS), respectively. Daily biogas and methane productions using palm kernel cake and palm kernel shell as substrates are depicted by Fig. 11 and Fig. 12 respectively. From this laboratory scale study, it can be concluded that cassava tuber, cassava peels, and palm kernel cake can be used in an ecologically sound way as substrates for anaerobic digestion.

The production of biogas from peels of watermelon (WP), banana (BP) and potato (PP) was also investigated using the same simple single-state digesters (Jekayinfa et al., 2015). Measured biogas yields for WP, BP and PP were 0.46, 0.42 and 0.56 m^3/ (kg ODM) respectively after 30 days digestion time. Methane production from WP, BP and PP was 0.23 (49.8%), 0.24 (56.55) and 0.30 (53.2%) m^3 / (kg ODM) respectively.

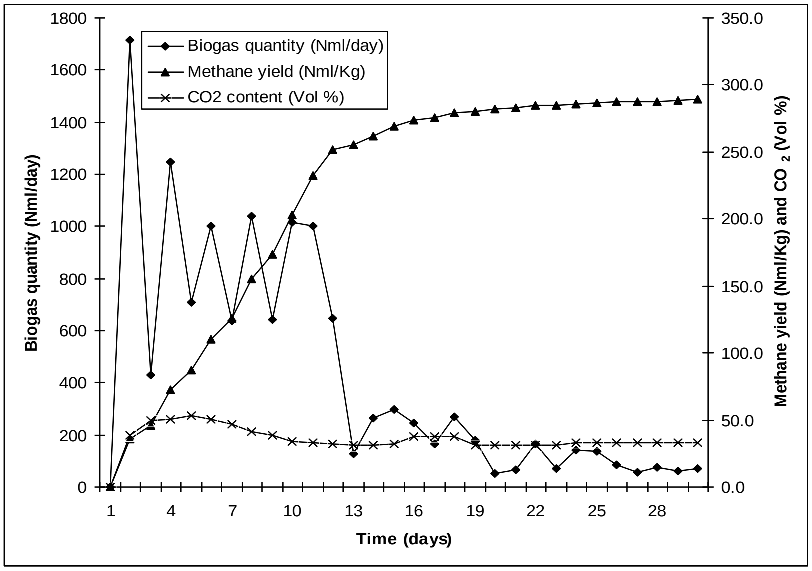


Fig. 11: Daily Biogas and Methane Production Using Palm Kernel Cake as Substrate

Source: Jekayinfa and Scholz (2013b).

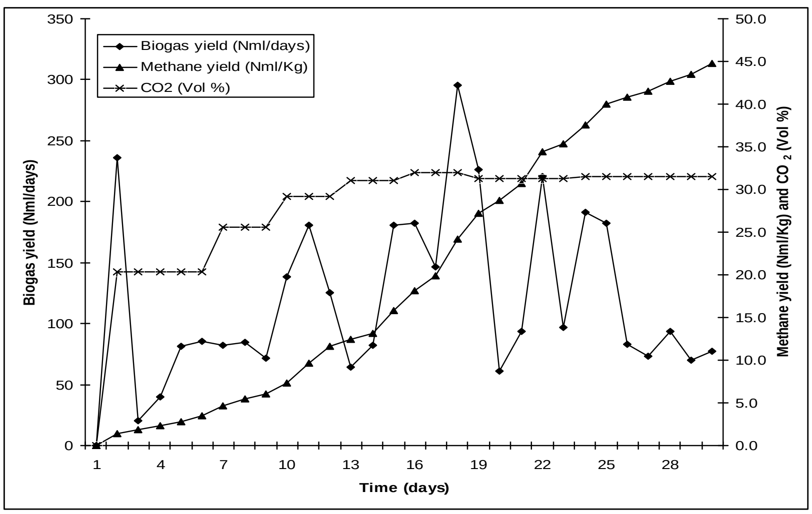


Fig. 12: Daily Biogas and Methane Production Using Palm Kernal Shell as Substrate

Source: Jekayinfa and Scholz (2013b).

Adebayo et al. (2015a) evaluated and compared the energy produced from anaerobic digestion of slurry of cow, pig and chicken waste by batch experiment at mesophilic temperature (37 ◦C) in batch anaerobic digestion test at 37°C according to German Standard Procedure VDI 4630 (2004). All samples were kept in the laboratory at a temperature of +3°C after size reduction (Plate 2) prior to feeding into the digester. Batch experiments were carried out in lab-scale vessels and replicated twice as described by Linke and Schelle (2000). A constant mesophilic temperature of 37°C was maintained through a climatic chamber (Plate 3). The study revealed that all the three animal wastes are good substrates for anaerobic digestion. The biodegradability of Chicken Waste (CW) was the highest with biogas and methane potentials of *493.08 L/(kg oDM)* and *328.19 LCH4/(kg oDM)* respectively.

In a similar experiment, three crop residues (maize stalk, maize cob and rice straw) were also subjected to anaerobic digestion using the same laboratory scale batch digester (Adebayo et al., 2015b) . It was concluded after the study that the three selected crop residues are good substrates for anaerobic digestion and the biodegradability of maize cob was the highest with biogas and methane potentials of *514.31 L/(kg oDM)* and *324.54 L/(kg oDM)* respectively at mesophilic temperature. It was also established that maize cob has the highest energy yields when compared to maize stalk and rice straw.

Plate 2: Size Reduction for effective fermentation
Source: Adebayo et al. (2015a)

Plate 3: Batch Experimental set-up
Source: Adebayo et al. (2015a)

An attempt was made by Adebayo, et al. (2012 and 2015c) to study the effect of organic loading rate (OLR) on biogas yield using cow slurry as a single substrate at mesophilic (37°C) temperature in a long time experiment with Continuously Stirred Tank Reactor (CSTR) (Plate 4). The experiment was run continuously for 140 days. It was observed that the biogas and methane yields decreased with increase in the organic loading rate after the reactor had attained stability. Both biogas yield and CH_4 in the biogas decreased with the increase in OLR. The biogas produced by cow slurry was found to have an average methane (CH_4) content of 58%. It was concluded that organic loading rate has a decreasing effect on the biogas and methane yields in a continuously tank reactor experiment at mesophilic temperature.

Plate 4: Set up of Continuously Stirred Tank Reactor (CSTR)
Source: Adebayo et al. (2012 and 2015c)

Co-digestions of various agricultural residues are also feasible. According to Agunwamba (2001), co-digestion is the simultaneous digestion of more than one type of waste in the same unit. Co–digestion is the simultaneous digestion of a homogenous mixture of two or more substrates. The most common situation is when a major amount of a main basic substrate (e.g. manure or sewage sludge) is mixed and digested together with minor amounts of a single, or a variety of additional substrates. Better digestibility, enhanced biogas production/methane yield arising from availability of additional nutrients, improved buffer capacity with stable performance as well as a more efficient utilization of equipment and cost sharing have been highlighted as part of the advantages of co-digestion (Agunwamba, 2001).

It has been shown that co-digestion of banana and plantain peels, spent grains and rice husk, pig waste and cassava peels, sewage and brewery sludge, among many others, have resulted in improved methane yield by as much as 60% compared to that obtained from single substrates (Ezekoye and Okeke, 2006; Ilori et al., 2007; Adeyanju, 2008). Anaerobic digestion from batch digester containing varying ratio of mixture of cow slurry and maize stalk was studied at mesophilic temperature (37ºC) (Adebayo et al., 2014a). Co-digestion of cattle slurry with maize stalks was found to have methane concentrations of 69.66, 70.24 and 66.98% at cattle slurry/maize stalks combinations of 3:1, 1:1 and 1:3 respectively. The highest biogas yields (oDM) of 0.426 m^3/kgoDM was obtained at the mixing ratio of 3:1; therefore the mixing ratio of 3:1 is recommended as the optimal for the co-digestion of cattle slurry with maize stalks at mesophilic temperature. Other similar successful works of anaerobic co-digestion of different substrates include: cattle slurry with maize cob (Adebayo et al., 2013), pig slurry with maize cob (Adebayo et al., 2014b), pig slurry with maize stalk (Adebayo et al., 2015d).

Attempts have also been made to develop simple bio digesters using readily available raw materials. One of such digesters designed, constructed and used is a plug flow digester (Figs. 13 and Plate 5) (Adebayo et al., 2014c). The Plug flow digester designed had a constant volume, but produced biogas at a variable pressure. It consists of a narrow and long tank with an average length to width ratio of 5:1. The inlet and outlet of the digester were located at opposite ends, with the inlet at an angle 45° to the horizontal floor. A rubber gasket was used to seal the reactor from the atmosphere. This prevents any form of leakages or loss of gas from the reactor for efficient collection of the biogas produced. Finally, the body of the plug flow digester is covered with black insulator to prevent radiation of heated water to the outside.

This reactor is augmented with recirculation capability, allowing the effluent from the digesters to be reintroduced into the system through the pump. The test set-up is designed such that entry of atmospheric oxygen or escape of biogas is excluded. The Plug flow digester designed and fabricated was tested and found to be adequate for the production of biogas using cow dung. The methane (CH_4), Carbon dioxide (CO_2), Hydrogen Sulphide (H_2S) and Oxygen (O_2) concentration of the biogas produced were found to be 85.33%, 13.07%, 1.56% and 0.04% respectively.

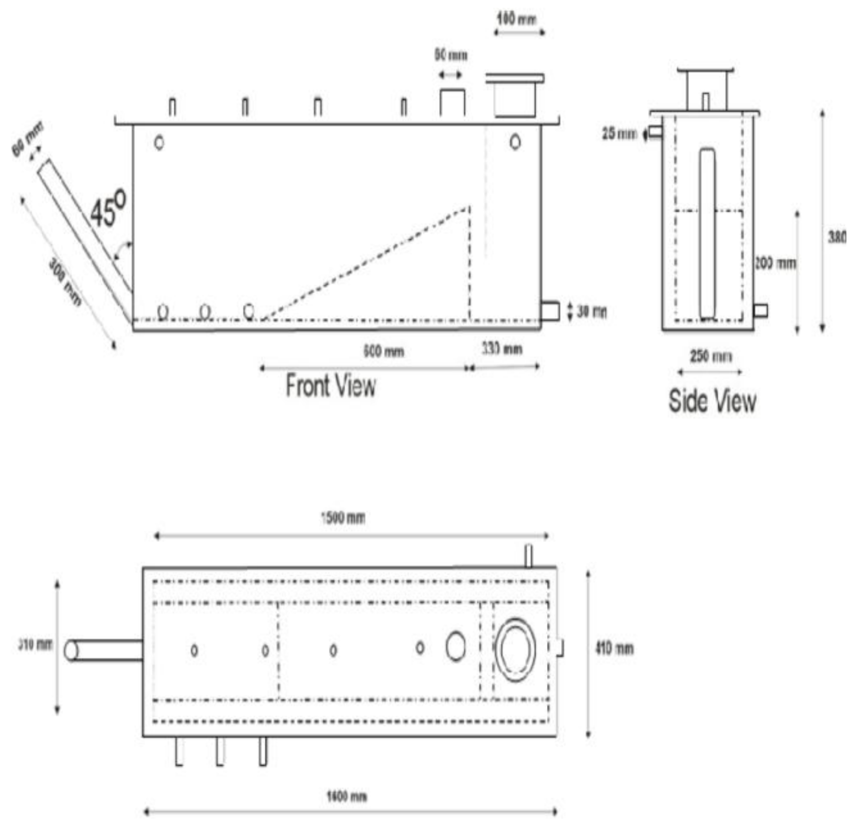


Fig. 13: Orthographic View of the Plug Flow Reactor
Source: Adebayo et al. (2014c)

Plate 5: The Plug Flow Reactor in Use
Source: Adebayo et al. (2014c)

Biodiesel Production

Biodiesel products have been reported as a very modern and technological area for researchers due to its environmental advantages (Marchetti et al., 2007). It is renewable, biodegradable, non-toxic, and typically produces about 65% less net carbon monoxide, 90% less sulphur dioxide and 50% less unburnt hydrocarbon emission than petroleum-based diesel (Margaroni, 1998; Conceicao et al., 2005; Jekayinfa and Waheed, 2008). When biodiesel is used as an additive, the resulting diesel fuel is named as B100 (pure biodiesel), B20 (20% biodiesel, 80% petroleum diesel), B5 (5% biodiesel, 95% petroleum diesel), and B2 (2% biodiesel, 98% petroleum diesel). The most common biodiesel blend is B20. Biodiesel's physical properties are similar to those of petroleum diesel (Ola and Jekayinfa, 2010).

Relevant feedstock availability in Nigeria, particularly palm kernel oil (PKO) and ethanol, has been reported (USDA, 1998). PKO is one vegetable oil in Nigeria, which had hitherto suffered neglect. Ethanol, on the other hand, can be produced from such crops as sugarcane, sorghum, corn, barley, and cassava common in Nigeria (Olafimihan et al., 2015).

Local palm kernel oil was investigated as a biodiesel fuel through potassium hydroxide catalyzed transesterification with ethanol (Alamu et al., 2009). Experiments were conducted at temperature range of 30 to 70 ^{o}C under reaction conditions of 100 g palm kernel oil, 1.0% potassium hydroxide, 20% ethanol (wt% palm kernel oil) and 90 min reaction time. Results show some palm kernel oil biodiesel properties to be within standard fuel specifications, while average palm kernel oil biodiesel yields of between 59.0% and 94.4% were obtained for the respective range of temperatures used. Optimal palm kernel oil biodiesel yield occurred at 60^{o}C. The effect of KOH concentration on PKO biodiesel yield was also studied, with a view to identifying the catalyst concentration corresponding to optimal process yield (Alamu et al., 2007a and 2007b). It was concluded from the results of the study that the KOH concentration of 1.0 % gave the maximum PKO biodiesel yield (95.8 %) and is therefore recommended as optimum, within the constraint of the typical transesterification process parameters used.

In another laboratory experiment, effect of ethanol–palm kernel oil ratio on alkali-catalyzed biodiesel yield was studied (Alamu et al., 2007c and 2008). A maximum PKO biodiesel yield of 96% was obtained with ethanol–PKO ratio of 0.2 under typical transesterification reaction conditions of 60^{o}C temperature, 120 min duration and 1.0% alkali catalyst (KOH) concentration.

Bio-ethanol Production

Ethanol can derive from any material which contains sugar. Bioethanol production involves acid hydrolysis, enzyme hydrolysis, fermentation and distillation processes. The raw materials used in the production of ethanol via fermentation are mainly classified into three types as sugars, starches, and cellulose materials. Sugars (extracted from sugarcane, sugar beets, molasses, and fruits) can be converted into ethanol directly. But starches (from corn, cassava, potatoes, and root crops) and cellulose (from wood, agricultural residues and paper mills) need to be pre-treated prior to fermentation. Olafimihan, et.al. (2015) investigated the possibility of producing ethanol from corn cobs peels, groundnut shells and plantain peels. Ethanol was produced from 500.0 g each of the ground residues collected at a dump site in Ogbomoso at different temperatures (25, 30, 35 and 40ºC) using acid hydrolysis, fermentation and distillation. The results showed that the volume of ethanol produced from the three residues increased with temperature up to 35ºC and began to decrease with temperatures. The highest volumes of ethanol (21.50, 14.50 and 14.50 ml) were obtained at a temperature of 35ºC from plantain peels, groundnut shells and corn cobs respectively and the lowest volumes (16.0, 13.0 and 10.0ml) were obtained at 25ºC from plantain peels, groundnut shells and corn cobs respectively. It was also observed that plantain peels out of the three residues produced the highest volume of ethanol at all temperatures.

Solar Energy Applications on the Farm

Solar energy can supply and/or supplement many farm energy requirements. It is applicable in gran drying. The basic components of a solar dryer are an enclosure or shed, screened drying trays or racks, and a solar collector (Waheed et al., 2011). With proper planning and design, solar air/space heaters can be incorporated into farm buildings to preheat incoming fresh air. Solar water heating systems may be used to supply all or part of hot water requirements on a dairy farm. Using the sun for cooling is an excellent application for solar energy because the air conditioning load corresponds with daylight hours (Waheed and Jekayinfa, 2005). Another application of solar energy is in solar cookers. Solar cookers use sunlight for cooking, drying and pasteurization. Solar cookers can be grouped into three broad categories: box cookers, panel cookers and reflector cookers (Durowoju and Jekayinfa, 2004). Solar electric, or photovoltaic (PV), systems convert sunlight directly to electricity in applications such as electrical fencing, lighting, and water pumping on the farm. Solar energy can be used for water distillation, water disinfection, and water stabilization to treat waste water without chemicals or electricity, for detoxification of contaminated water via photolysis and sewerage treatment at the community level (Solar Manual, 2009).

Development and Maintenance of Agricultural Machines

Development of Local Agricultural Machines

Farms use a lot of equipment, and all of it uses energy in one form or the other. In some cases, increasing the efficiency of a single piece of equipment or an operation can result in significant energy savings, especially over time. One of the way to do this is in the development of indigenous farm machines conceived from appropriate technologies that are environmentally friendly, energy-efficient, and are people-centered instead of machine-centered. A few agricultural machines useful in agricultural production and post-harvest operations have been developed in collaborations with my students and colleagues. These include: centrifugal palm-nut cracker (Ojediran and Jekayinfa, 2002), motorized plot harvester (Jekayinfa, 2002), pedal-operated cassava grater (Jekayinfa et al., 2003), extractor for small and medium scale fruit juice processors (Olajide et al., 2003), parabolic concentrator-solar cookers (Durowoju and Jekayinfa, 2004), grain screw dispensing machine (Jekayinfa, 2005), mango stone decorticator (Jekayinfa and Durowoju, 2005), crop residue chopper (Fig. 14) (Jekayinfa et al., 2012), electric crop dryer (Onifade et al., 2016) and sugarcane juice extractor (Fig. 15) (Jekayinfa et al., 2017).

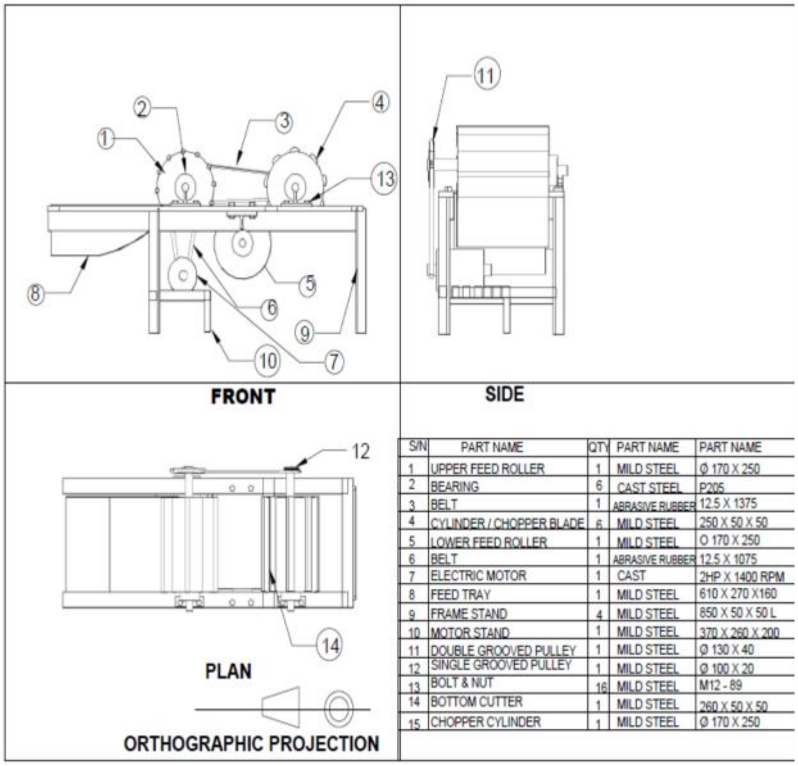


Fig. 14: Orthographic View of the Developed Crop Residue Chopper
Source: Jekayinfa et al. (2012)

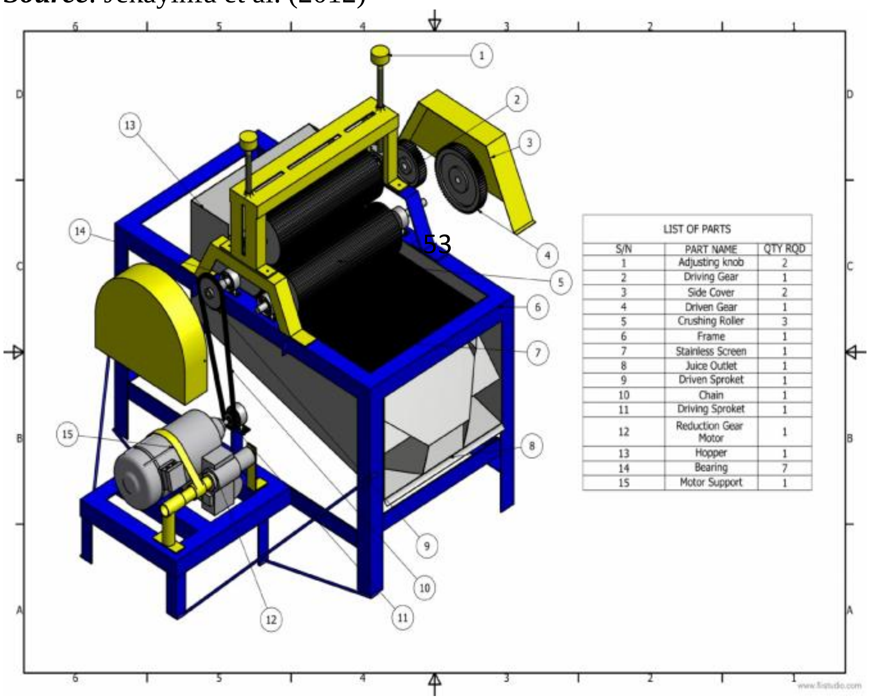


Fig. 15: AutoCAD view of the Sugarcane Juice Extractor
***Source*:** Jekayinfa et al. (2016)

Agricultural Machinery Management

Proper agricultural machinery management requires keeping them in good working conditions, having them repaired or reconditioned as and when due, selecting suitable types and sizes, keeping cost record and controlling it (Dauda and Ashami, 2000; Adebiyi et al., 2005). Maintaining agricultural machines is not a "free lunch" as it requires some mechanical engineering workshop tasks, which are high energy demanding (Adeyemi and Jekayinfa, 2004) and cannot be continued for prolonged period without rest stops.

An energy study of some mechanical tasks such as blacksmithing, welding, filing, hacksawing and grinding, in Agricultural engineering workshops was carried out (Jekayinfa and Adebayo, 2010). Subjects with four different age groups were calibrated on a bicycle ergometer in different weather conditions. The subjects were then engaged in the various tasks in turn under similar environmental conditions. Their heart rates were measured and the energy requirements calculated. The studies showed that blacksmithing - forging (with long- handled hammer) required 7.76kJ/min, forging (with short handled hammer) required 8.61kJ/min, fire poking with bellows required 6.60kJ/min, hack-sawing required 6.14kJ/min, welding (in bending posture) 8.45KJ/min, welding (standing posture) 7.14KJ/min and grinding (hand grinder) required 5.90KJ/min. It was revealed also that bending posture and working in hot environments increase human energy requirements.

A few research works relating to agricultural machinery management have been carried out with a view to making replacement decisions and for overall farm budgeting (Jekayinfa et al., 2005a; 2009). The studies had proven that a reduction in repair costs by careful operation and adequate maintenance could result in a significant reduction in machines ownership costs. Mechanization of agricultural operations and use of modern machinery and appropriate agricultural land development techniques have also been found to reduce energy consumption per ton of yield of crop, and resulted in lower cost of production (Taiwo and Jekayinfa, 2005, 2018).

Another important area of machinery maintenance is in prevention of corrosion of plain carbon steel mostly used for machinery fabrication in Nigeria (Alli and Faborode, 1993; Jekayinfa et al., 2005b; Chukwujekwu, 1998). This is a result of some aggressive ions present in raw agricultural and food products, which may attack the steel components of processing machinery, resulting in their untimely failure in service. The formation of scale and corrosion on equipment surfaces restricts water flow, clogs equipment and reduces system efficiency. The results can be costly — increased energy consumption, greater downtime, additional maintenance and reduced equipment life.

Jekayinfa et al. (2003b and 2005c) investigated the effect of cassava fluid on corrosion performance of mild steel. The investigation involved periodic weight loss measurements of 0.18 per cent carbon and 0.36 per cent carbon steel rods as they were exposed to cassava fluid. Corrosion intensity in both cases, increased with duration of immersion. Generally, there was low level of corrosion resistance (high corrosion rate) by the two steel materials. The implication of this is that mild steel materials are unsuitable for use in cassava processing without some forms of surface treatment.

Concluding Remarks

Mr. Vice-Chancellor Sir, everyone loves a free lunch – but the problem is that free lunch almost always has hidden costs. Industrial agriculture is an example of this wishful free-lunch thinking, as revealed in this short lecture. Almost all activities in the agricultural food system depend on some form of energy, which is currently mainly provided by fossil fuels. The need to use scarce natural resources efficiently, reduce greenhouse gas emissions and minimize energy costs highlights the importance of the energy efficiency issue: using less energy to provide the same level of output and services.

The industrialized agricultural system continuously pushes ahead with a focus on higher agricultural yields using fossil fuel-derived inputs, ostensibly with the goal to produce enough to feed the ever increasing population, but there are some externalities that often go unaccounted for in the process. When the real costs of expensive and typically unaccounted for externalities like greenhouse gas emissions from deforestation and fossil fuel use are factored in, what some might consider "free" are really not.

To reduce the burden of these unaccounted for consequences, the agricultural food sector must become more efficient to feed more people. This can be achieved either through energy efficiency measures or through the application of renewable energy. In this wise, an energy audit is very important. A Farm Energy Audit is an essential management tool in developing a comprehensive energy plan for a farm or rural business. As it has been demonstrated in the outcomes of some of the studies reported in this lecture, a farm energy audit can pinpoint areas for reducing energy costs and energy use**.** A farm energy audit can also improve operational efficiency as well as identify potential areas for renewable energy application.

Some of the reports included in this lecture identify opportunities for achieving energy savings through improved management practices, recovery of energy from agricultural waste and adoption of renewable energy. Agricultural sector can play a key role in the progress of renewable energy sector in Nigeria and around the world as it is capable of providing large areas where renewable energy projects can be cited and utilised, and is also the predominant feedstock source for biomass energy programmes.

Just as there is no free lunch, there is no free profit from agricultural ventures. Insufficient mechanical and electrical energy is available for agriculture in developing countries such as Nigeria, and hence the potential gains in agricultural productivity through the deployment of modern energy services are not being realized. To increase agricultural productivity in Nigeria to the level enjoyed by farmers in developed countries, our agricultural practices have to be fully mechanized; more energy has to be used efficiently in crop and animal production, in processing and storage, in tapping renewable energy from agriculture, in the manufacture of energy-saving farm machines, in machine maintenance and repairs and, in construction and maintenance of farm buildings. The farm is indeed a thermodynamic system wherein there is 'No Free Lunch".

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1. **Iwo to fe wa la o ma sin titi**
   Oluwa Olore wa
   Iwo to n so wa n'nu idanwo aye
   Mimo, logo ola re

   Baba, iwo l'a o ma sin
   Baba, iwo l'a o ma bo
   Iwo to fe wa l'a o ma sin titi
   Mimo l'ogo ola re.

2. **Iwo to nsure s'ohun t'a gbin s'aye**
   T'aye fi nrohun je o
   Awon to mura lati ma s'oto
   Won tun nyo n'nu ise re.

3. **Iwo to nf'agan lomo to npe ranse**
   Ninu ola re to ga
   Eni t'o ti s'alaileso si dupe
   Fun 'se ogo ola re

4. **Eni t'ebi npa le ri ayo ninu**
   Agbara nla re to ga
   Awon to ti nwoju re fun anu
   Won tun nyo n'nu ise re.

5. **F'alafia re fun ijo re l'aye**
   K'ore-ofe re ma ga;
   k'awon eni tire ko ma yo titi
   ninu ogo ise re. Amin.

(Credit for song lyrics: http://samosalau.com.ng/iwo-to-fe-wa-la-o-ma-sin/)

The Vice-Chancellor Sir, Ladies and Gentlemen, I thank you most sincerely for your attention. For this special celebratory occasion, there will be **free lunch**.

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