INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN 2278 – 0211 (Online)

Economic Assessment of Utilizing Diesel Derived from Used Lubricating Oil for Power Generation in Ghana

Richard Kingsley Padi
Process Design Engineer, Department of Engineering, Stable Corps Company Limited, Kumasi, Ghana

Abstract:
There is potential to recycle used oil (UO), waste lubricating oils from automobiles or machineries to produce diesel fuel (DF) that can contribute to energy supply in Ghana. However, very little is known about the economics of recycling UO to DF (Rec-UO-to-DF) and the DF use thereof for power generation (DF-power) in Ghana. This study assessed the economics of Rec-UO-to-DF and DF-power in Ghana under 2016 economic conditions, through developing process and economic models based on literature. The economics were assessed relative to prevailing diesel price ($0.79/l) and grid power prices ($0.08-0.24/kWh- residential and $0.24-0.41/kWh- commercial). Sensitivity analysis was undertaken to establish impacts of UO pricing on DF prices, and DF pricing on power prices. Maximum Expected Selling Price of- UO (MESP-UO) and -DF (MESP-DF) required for economic viability of the Rec-UO-to-DF and DF-power respectively were determined. The results showed a 12000 l UO/day recycling facility could produce ~8420 l DF/day, which could generate 1250 kW power via a diesel generator. UO price was found influential on DF price- 10% increase in UO price yields 3.2% increase in DF price. The MESP-UO was found at $0.21/l. Regarding DF-power, 10% increase in DF price results in 7.5% increase in power price, suggesting high reliance of process economics on the DF price. Instabilities in fuel prices therefore implies high uncertainties regarding economic viability. At prevailing DF price ($0.79/l), power price for profitability was found at $0.31/kWh (within commercial range), implying DF-power is economical for only commercial use. Extension of DF-power to residential users would require 31% reduction of prevailing DF price, which could be feasible if Rec-UO-to-DF process acquires UO at $0.05/l (~24% of MESP-UO). Enforcing environmental regulations on UO management could help lower UO prices, which will promote its recycling to DF for DF power, and thus contribute to sustainable power supply.

Keywords: *Used oil, recycling, diesel fuel, power generation, economic assessment*

1. Introduction

Modern energy, such as electricity (termed power) and fossil fuels, is essential for developmental activities such as healthcare and industrialization, thus facilitates socio-economic growth [i]. Provision of modern energy is therefore a global concern that is even higher in Africa, which is considered the least performing continent with regards to meeting its modern energy demands amidst abundant energy resources[ii].For instance, estimates suggestabout57% of the African population lack access to electricity, and nearly 68% rely on traditional solid biomass for cooking [ii]. It is estimated that energy demands in sub-Saharan Africa (SSA) increased by approximately 45% from the year 2000 to 2012 [iii].

Similarly, in Ghana, the power demand is estimated to increase by 10 to 15% annually [iv], and is attributed to factors including rapid population growth, and expansions in corporate and industrial sectors [v, vi]. Governmental commitment to energy security resulted in improvements in access to electricity, which reflected in electricity access rate of 70% [ii]. However, achieving the generation capacity to keep up with growing power demands remain a challenge[vi]. The national power mix is dominated by hydro, with a contribution of~ 65%, followed by fossil fuel (crude oil, diesel and natural gas)based thermal plants-which supplies nearly 35% of the national power [v]. The reliability of the hydro power is dependent on uncontrollable weather conditions, and thus an avenue for instability in the hydro power supply. For instance in 2014, adverse weather impacts on the hydro dams contributed to shortfalls of approximately 6.5 % of the installed hydro capacity of 1580 MW[v]. The unreliability in the hydro power supply has been a compelling factor for the implementation and expansion of thermal power in recent years [v, vii]. However, the thermal power as an alternative to the hydro, also faced unexpected challenges including abysmal supply of the required natural gas by Nigeria, as well as instability in oil prices, which collectively contributed to about 13% of total thermal power capacity (approximately1260 MW)being unrealized in 2014 [v]. Ensuring stability of the thermal power supplies will therefore demand sustainable fuel resources and measures to absorb fiscal shocks due to unstable prices. A promising solution seems to be the local discovery and exploitation of oil and gas[vii]. However, considering existing economic constraints compels the selling of most of these resources abroad [ii], it is unlikely that utilizing the local oil and gas for the growing power demands can be sustained in the long-term.

In related developments, used oil (UO),which refers to any conventional oil from refining crude oil, or synthetic oil that has been physically or chemically contaminated by impurities in the course of its usage [viii, ix], has been suggested as an inexpensive resource for diesel fuel production [viii, x].In the context of this study, UO is limited to fossil based oils and entails exhausted (per the intended use)transmission oil, engine oil, and hydraulic oil (collectively termed lubricating oil)from automobiles or machineries[ix, xi]. The advancement in industrialization and the transport sector in Ghana resulted in high lubricating oil usage[xii]. Available data from the National Petroleum Authority indicates the total local consumption of lubricating oil in 2013 was nearly 45 million liters, all of which was imported [xii]. It is also estimated about 20% of lubricating oil is expended during its usage or service period [xii, xiii]. Therefore, under the assumption that the year 2013's consumption of lubricating oil remains same for other years, it can be projected that approximately 36 million liters of UO will be generated annually. Locally, almost all the generated UO are illegally dumped on lands around garages, or disposed-off into drains, which eventually ends up in water bodies [xii]. Typical impurities found in UO that pose environmental and health concerns includes heavy metals such as lead (Pb) and cadmium (Cd), sulfur, poly nuclear aromatics (PNAs) amongst others [xiv, xv]. Associated environmental and health detriments of such indiscriminate disposal of UO, due to the impurities, include long span soil infertility, diseases in man and animals from drinking or exposure to UO polluted water, and destruction of aquatic life [xiv, xvi]. Alternate uses and measures of secured disposal of UO will therefore help contribute to environmental sustainability and safeguard health of the populace.

Conversely, UO could be used as fuel in diesel engines, industrial boilers or kilns [vii, x]. However, direct combustion of used oil releases hazardous gases into the environment, thus demands reprocessing or recycling measures to lower the concentrations of the impurities to acceptable limits, prior to its use as fuel[viii, xvii, xviii].Some recycling approaches that are well understood and practiced include solvent extraction, distillation-clay, acid treatment, activated charcoal/clay, and acid-clay treatment, with the choice of approach informed by the type and concentration of impurities, or the end-use thereof [viii, xi, xiii, xix].The acid-clay process is known to be the most widely used for the production of diesel fuel[viii, xiii], and in some cases suggested as the best treatment approach [xx, xxi]. The conventional acid-clay recycling process mainly entails filtering off solid impurities, heating to remove water and other lighter impurities, treatment with acid to react with impurities such as metallic oxides, asphaltenes, and aromatics to form a separable sludge, and further treatment with activated clay as an adsorbent to eliminate mainly gum forming contaminants[viii, xi, xxi].Compared to other reprocessing approaches, the acid-clay process is said to be advantageous due to less complex process equipment demands and thus less initial investment costs, less skill requirement in process operations, and lower operating cost demands [xi]. However, environmental awareness in recent times is making the conventional acid-clay process less popular due to the formation of large volumes of acidic clay and sludge residues, which poses treatment challenges and high cost implications[viii, xi]. However, Beg et al. [xiii]suggested the introduction of an acid neutralization stage (with NaOH) after the acid treatment stage minimizes the acidic level of the formed sludge and clay. Also, incineration under controlled flue gas conditions and secured landfill disposal are said to be adequate management practices for the sludge and acid-clay, respectively[xi, xviii].Thus, this modified acid-clay process seems appropriate for Ghana, as the associated low economic and low technology requirement befits the developing economy.

Therefore, considering the immense quantity of UO generated in Ghana, production of diesel fuel (DF) from UO is envisaged to be a possible alternative to the challenges of instability in the supply and the prices of fuel for thermal power generation, and thus contribute to the sustainability of the thermal power supply in Ghana. However, little is known regarding the economics of such measures in Ghana. According to Chia-Yu[viii], the recycling of UO to DF (Rec-UO-to-DF) in the United States was profitable, though not substantial enough to attract more investors. Also, the profitability of Rec-UO-to-DF is said to be reliant on diesel prices [viii]. Therefore, the implementation of Rec-UO-to-DF for power generation in Ghana will demand a comparative economic assessment with the conventional diesel approach. Also, the economic assessment must address concerns on profitability of implementing such measures from the perspectives of all stakeholders-including traders of UO, investors in Rec-UO-to-DF facilities, and investors in the thermal power facilities. Of all the aforementioned stakeholders, the role of the UO traders is essential to sustain the UO as a raw material. Furthermore, considering the fact that presently the UO ends up in pockets of small quantities scattered around in various service stations, or in drains and consequently in water bodies [xii], an extensive labor network and incentive will be required to mobilize and transport the UO to the recycling site. Consequently, the delivered UO price that will make the Rec-UO-to-DF process economical assuming the produced DF is sold at the prevailing diesel price, termed Maximum Expected Selling Price of UO (MESP-UO), should be an important factor to be determined. Sensitivity analysis showing how the price of UO impacts on the price of the produced DF must therefore be performed. Also, the delivered DF price that will make the DF-based power generation (DF-power) process economical, assuming the generated power is sold at the maximum grid price, termed maximum expected selling price of DF (MESP-DF), must also be established. Thus, a sensitivity analysis demonstrating how DF price influences the power price, while ensuring profitability of the DF-power process, must be considered vital for assessment.

This study therefore assessed the economics of Rec-UO-to-DF, and the use of the DF in thermal power generation in Ghana, relative to prevailing prices of diesel and grid power. Additionally, the economics sought to establish applicable selling prices of UO, as well as tolerable prices of DF, with respect to economic viability of applications in power generation. These were achieved by developing process models for the Rec-UO-to-DF- and DF-power generation- processes, followed by their respective economic models. The findings from this study will provide a fundamental basis for stakeholders to actively deliberate on the use of DF from UO as a sustainable fuel for thermal power applications.

2. Materials and Methods

2.1. Conceptual Approach

In order to assess the economics of the recycling of UO to DF (Rec-UO-to-DF) and the DF-based power (DF-power) processes, process and economic models were developed for each referred process. The process and economic modeling approach considered was similar for both the Rec-UO-to-DF and DF-power processes, which is summarized in Fig. 1. The process modeling commenced with establishing the process configuration, involving the plant capacity and choice of process, in consultation with literature. This was followed with evaluation of the mass and energy balances, which was based on available literature or estimates. The results of the mass and energy balances were then used in sizing or specifying the process equipment. In developing the economic models, the results of the mass and energy balances were considered in estimating the Total Production Cost (TPC), while the sized or specified equipment costs, determined from various literature or manufacturers quotes, were used to estimate the Total Capital Investment (TCI), as detailed under section 2.3.The obtained TPC and TCI were then used to develop a cash flow spreadsheet in Microsoft Excel 2010, which was subsequently used for the Economic assessments.

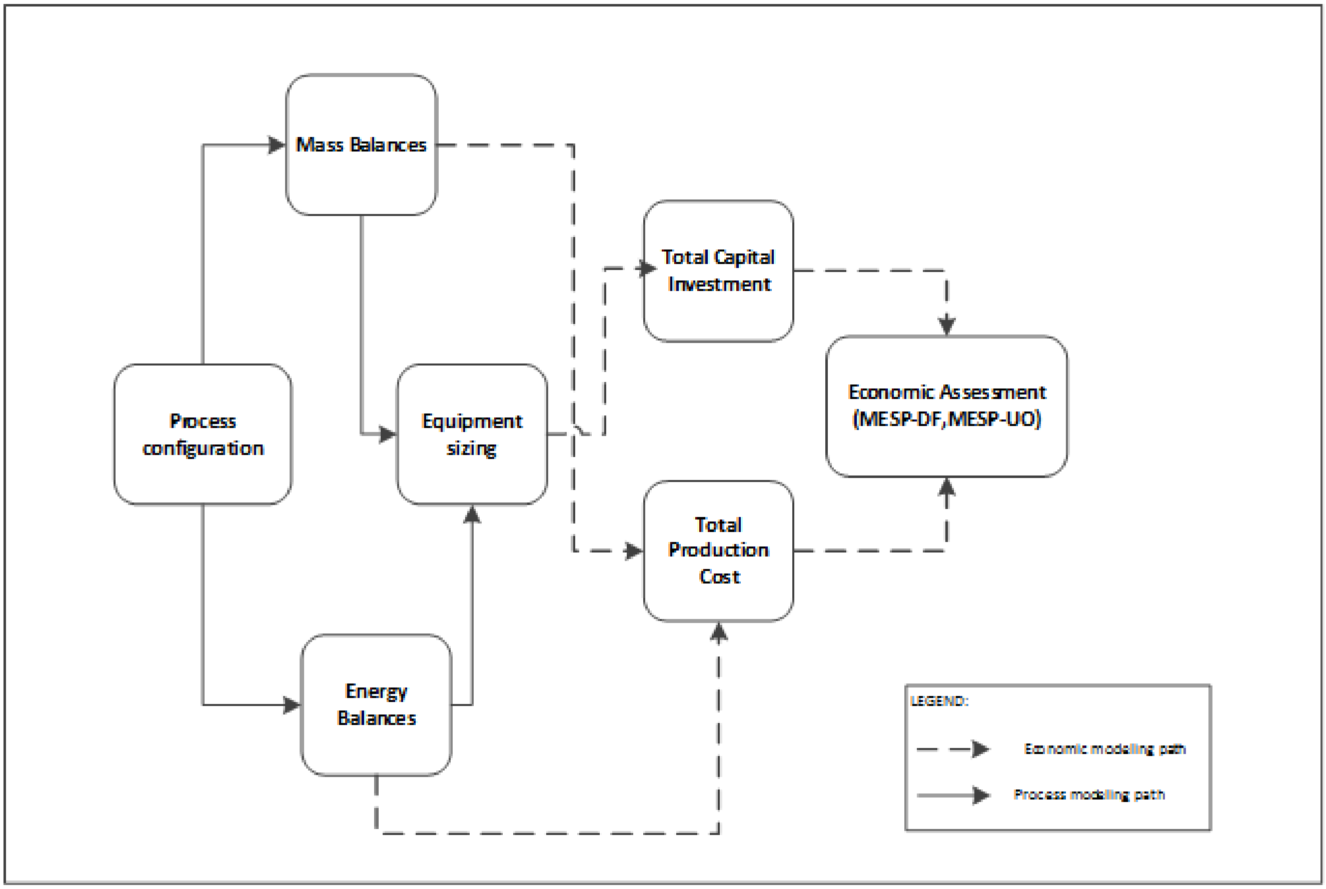

Figure 1: Conceptual Approach

For the economic assessments of the Rec-UO-to-DF, a maximum expected delivered price of UO to the facility assuming the produced DF is to be sold at prevailing diesel price (MESP-UO) was to be evaluated. This was achieved by performing sensitivity analysis showing how the produced DF's price responds to variations in the selling price of the UO, under conditions of an economically viable process. The MESP-UO was subsequently obtained as the price of UO found at the prevailing price of diesel from the results of the sensitivity analysis. Similarly, in the economic assessments of the DF-power process, the maximum expected price of delivered DF to the power facility, under assumption of selling the generated power at the maximum grid price (MESP-DF), was required. A sensitivity analysis illustrating how the prices of DF impacts on the power prices, while maintaining conditions of economic viability of the process, was performed. The MESP-DF was obtained from the findings of the sensitivity analysis as the prices of DF that correspond to the prevailing grid power prices.

2.2. Process Descriptions and Modeling

2.2.1. Recycling Used Oil to Diesel Fuel (Rec-UO-to-DF) Process

The Rec-UO-to-DF process considered in this study was a modified acid-clay process, mostly based on the studies by Beg et al. [xii], as summarized in Fig. 2. The process begins with pumping the UO from a storage tank into an acid treatment tank (agitator tank), where it is mixed with a predetermined amount of 98 wt.% sulfuric acid (H_2SO_4)solution- based on composition of the oil[xi, xiii]. The mixture is then stirred for about 10 minutes, after which it is left without interruption for about 2 hours; a period during which asphalt and acidic sludge, formed by reactions between the acid and some impurities such as sulfur and metal salts, sediments for collection [xiii].The acid treated-UO is then pumped to a neutralization tank (agitator tank), where a calculated amount of sodium hydroxide (NaOH) is added and left undisturbed for about 30 minutes[xiii]. The NaOH reacts with some acidic components of the oil to produce salt and water. Also, sludge forms and settles for collection during the neutralization process. The next stage is the activated-clay contact stage, which entails addition of ground activated clay (particle size of about 0.5 mm) to the oil in proportions of about 15wt.% of oil[xi, xxii] in an agitator tank. The clay-oil mixture is then thoroughly stirred and left for a contact period of about 25 minutes [xxii], during which the clay adsorbs impurities to form a sludge that is separated from the oil. The activated-clay treated oil is then filtered to eliminate solid matter by means of a filter press[xvii]. The final step entails removal of water from the oil to improve its fuel properties. This is achieved by heating the oil to a temperature of about 170^0C in a closed steel vessel that is directly fired by diesel burners. During the heating, it is ensured that the temperature is held at an intermediate temperature of 100^0C for the evaporation of water[xvii].The subsequent increase in the temperature to 170^0C ensures the evaporation of lighter organic impurities that might have been added to the used oil by the suppliers [xvii].The final oil product, that is the diesel fuel, is subsequently cooled to about 30^0C by means of cooling water jackets, for storage.

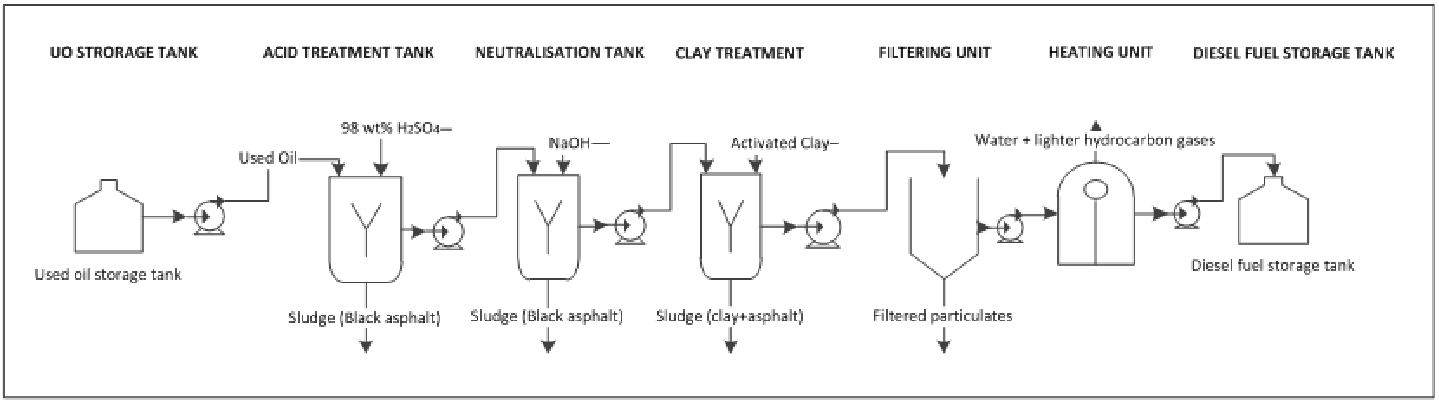

Figure 2: Modified Acid-Clay recycling process for production of diesel fuel from used oil (Adapted from Beg et al. [13])

In the process modelling, the considered capacity of the Rec-UO-to-DF facility was based on factors related to securing the UO feedstock. The collection of UO nationwide for supply to the Rec-UO-to-DF facility will require extensive transportation, and thus perceived high cost of transportation. Thus, a decentralized recycling approach in all ten regions in Ghana was considered in this study. A regional production capacity of 12000 l UO/day was therefore considered based on literature and conservative assumptions as summarized in Table 1.The mass and energy balances were estimated based on experimental findings of Hayalu [xi], as well as conservative assumptions based on reports, as summarized in Table 2.

Parameters	Value
National annual lubricant oil consumption[1]	45 million l/yr
National annual UO generated[2]	36 million l/yr
Regional annual UO generated[3]	3.6 million l/yr
Plant operating days per annum	300 days/yr
Rec-UO-to-DF plant's daily capacity	12000 l UO/day
[1] Based on the assumption that consumption of lubricating oil in the year 2013 (reported to be 45 million liters by Mensah-Brown [xii]) remains constant for other years; [2] Estimated based on an assumption of 20% of lubricant oil losses during usage [xii, xiii]; [3]Securing the UO raw material is vital to sustaining plant operation. It was therefore assumed the plant can secure only regional UO due to perceived challenges and high cost of transporting UO from other regions. Also, equal UO generating capacities in all 10 regions in Ghana was assumed	

Table 1: Assumptions considered in estimating the capacity of the Rec-UO-to-DF plant

<table>
<tr><th colspan="3">MASS BALANCE</th></tr>
<tr><th>Process stage</th><th>Components/Chemicals</th><th>Daily amounts (apart from NaOH & Activated clay given in kg, all other values are given in l)</th></tr>
<tr><td rowspan="3">Acid Treatment Step</td><td>98 wt.% H_2SO_4</td><td>2400 [1]</td></tr>
<tr><td>Sludge</td><td>1680</td></tr>
<tr><td>Acid treated oil</td><td>10320 [2]</td></tr>
<tr><td rowspan="3">Neutralization Step</td><td>NaOH (assumption of 95% purity)</td><td>900[3]</td></tr>
<tr><td>NaOH neutralized oil</td><td>9910[4]</td></tr>
<tr><td>Sludge</td><td>410</td></tr>
<tr><td rowspan="3">Activated Clay Treatment Step</td><td>Activated clay (Bentonite clay)</td><td>1340[5]</td></tr>
<tr><td>Activated clay treated oil</td><td>9490[6]</td></tr>
<tr><td>Sludge + clay</td><td>2090</td></tr>
<tr><td rowspan="2">Filtration Step</td><td>Filtered oil</td><td>8540[7]</td></tr>
<tr><td>Impurities</td><td>950</td></tr>
<tr><td rowspan="2">Heating Step</td><td>Diesel fuel product</td><td>8420</td></tr>
<tr><td>Water</td><td>120 [8]</td></tr>
<tr><th colspan="3">ENERGY BALANCE</th></tr>
<tr><td colspan="2">Electricity for equipment such as pumps.</td><td>480 kWh[9]</td></tr>
<tr><td colspan="2">Daily fuel for heating stage (assumed to be conventional diesel fuel)</td><td>0.002l[9]</td></tr>
<tr><td colspan="3">[1] Specified as 20% (v/v) of UO feed [xi]; [2] Specified oil recovery of 86% (v/v) of UO feed [xi]; [3] According to Hayalu [xi], approximately 1/4 of the H_2SO_4 remained unreacted at the acid treatment step. Hence, NaOH was estimated as stoichiometric equivalent required to neutralize the unreacted H_2SO_4[xi]; [4] Specified oil recovery of 96% (v/v) of oil fed to neutralization step [xi]; [5] Estimated based on optimum of 15 wt.% of oil and density of the oil fed at 900 kg/m^3[xi]; [6] Specified oil recovery of 95.8 % (v/v) of oil fed to clay treatment unit [xi]; [7] Based on assumed oil recovery of 90% (v/v) of the oil fed [xxiii] ; [8]Estimate based on assumption of total evaporation of water content of 1.4 % (v/v) [xii]; [9]Estimated based on assumption that the electricity and heating energy demands will not vary from those of an acid-clay reprocessing of used oil to base oil estimated at 0.04 kWh/l base oil and 440 kJ/ton base oil respectively[xvii].</td></tr>
</table>

Table 2: Mass and energy balances for the considered 12000 liters UO/day Rec-UO-to-DF plant

2.2.2. Diesel fuel-based power generation (DF-power) process

A diesel engine generator (diesel generator) was the considered power technology in this study, due to its ease of operation and less technical know-how demands [xxiv], thus compatible with the socio-economic conditions of Ghana. The main components of a diesel generator are a prime mover and an alternator[xxv]. According to Wolfgang [xxv], the prime mover is an internal combustion engine which converts the fuel into mechanical energy. This process begins with injection of the fuel into the engine cylinder where it is atomized and mixed with compressed intake air. Moving pistons in the cylinder compresses the intake air until the fuel ignition temperature is attained, resulting in a controlled internal explosion within the cylinder when the fuel is introduced. The hot combustion gases of the explosion then expands pushing against a piston connected to a shaft mechanism, hence results in rotation of the shaft. The rotating shaft is coupled to the alternator. In the alternator, a network of magnets connected to the shaft (armature) rotates to produce a rotating magnetic field, which results in generation of the electricity by induction via a stator (a winding of coils over an iron core) in conventional generators [xxv]. In operation of the diesel generator, a variation in the speed of shaft implies fluctuations in the voltage of the generated power. To ensure steady power generation, control mechanisms entailing a governor and actuator, which controls the speed of the shaft by regulating the flow rate of fuel (thus the combustion gases), and a voltage regulator are engaged in operation of the generator[xxvi], as shown in Fig. 3. Manufacturers of diesel generators usually supply pre-assembled primary and auxiliary components such as the control mechanisms, the fuel storage and conditioning, and the electrical switchgear and distribution systems[xxiv], collectively called a genset.

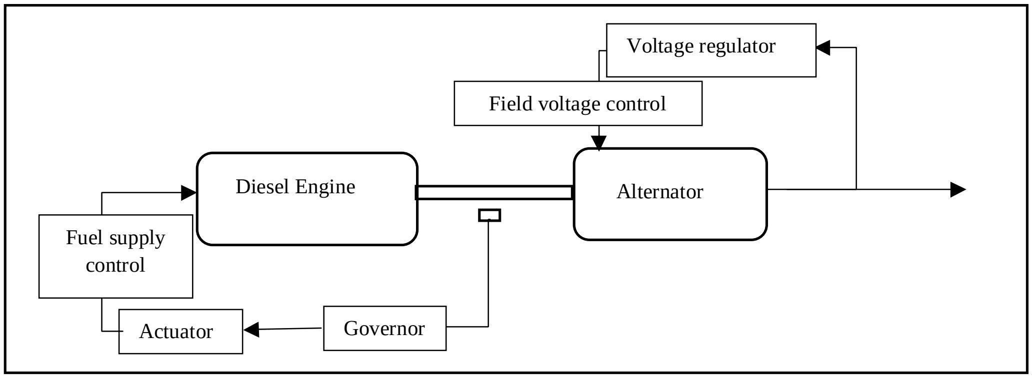

Figure 3: Diagram showing key components of a diesel generator (Source: Dewadasa et al. [26])

According to Beg et al. [xiii], the DF produced from the acid-clay recycling process (adopted in this study) had similar fuel properties to conventional diesel. Therefore, in the process model, sizing of the diesel generator was based on the assumption that the produced DF from the Rec-UO-to-DF facility will be solely used in the power generation (DF-power) plant. Thus, the estimated daily diesel fuel production of 8420 l/day (see details in Table 2) was considered as the fuel requirement of the power plant. The power plant was also assumed to operate in a regular power (base load) supply mode, and not as a standby option. Accordingly, the diesel generator capacity was estimated to be 1250 kWas elaborated in Table 3.

Parameter	**Value**
Daily diesel fuel supply	8420 l/day
Hourly diesel fuel supply[1]	350 l/hr
Corresponding diesel generatorsize[2]	1250 kW
[1] Considering the intended operating mode of the power plant is as a base load power supply, it was assumed that the plant was operated at full load and 24 hours per day; [2]Projected based on estimation of a diesel generator with a fuel consumption rate of ~340 ldiesel/hr generating 1250 kW power at full load operation [xxvii].	

Table 3: Assumptions in sizing the diesel generator

2.3. Process Economics

The MESP-UO and MESP-DF are dependent on operating costs, capital investment, revenue from product sales, and economic assumptions [xxviii], thus their estimation will require cash flow analysis over the plant life of the process. Therefore, the sensitivity assessment to determine the MESP-UO and MESP-DF involves a discounted cash flow rate of return (DCFROR) assessment. The DCFROR was performed using the cash flow spreadsheet developed from the estimated Total Capital Investment (TCI) and Total Production Cost (TPC). The economic assessment was based on fiscal conditions of year 2016- where US$ 1 was equivalent to GH¢ 3.98 as at November 2016 [xix].

The TCI entails the cost of the built plant ready for start-up, termed Total Fixed Capital- TFC, and the capital required for initial operation of the facility, termed Working Capital- WC[xxx]. The TFC consist of the cost of equipment, installations, civil work, piping, and contractor’s fees amongst others [xix].Cost of the sized equipment (based on the mass and energy balances) were obtained from literature, or manufacturer’s quote [xxxi, xxxii]. The obtained equipment cost, together with suggested appraisal measures for similar fluid processing[xxx], and diesel generator power plants [xxxiii, xxxiv],was used to estimate the TFCs as detailed in Table 4. The WC was estimated as the total production cost (TPC) for one month [xxx]. The TCI was subsequently obtained by summing the TFC and the WC.

Cost Component	**DF-power Plant Appraisal Factors**	**Rec-UO-to-DF Plant Appraisal Factors**
Direct Plant Cost (DPC)[1]	135% of Purchase Cost of Genset [4]	132% of Purchased Equipment Costs (PEC) [6]
Installation &Construction Cost (ICC)[2]	34% DPC[4]	45% of PEC + 10% of DPC [6]
Indirect Plant Cost (IPC)[3]	35% of ICC [5]	30% of PEC +8% of DPC [6]
Total Fixed Capital (TFC)	DPC + ICC + IPC[5]	DPC + ICC + IPC[5]
Working Capital (WC)	Total Production Cost (TPC) for a month [6]	TPC for a month[6]
Total Capital Investment (TCI)	TFC + WC	TFC+WC
[1] Includes costs of equipment, installation, piping, civil works, structures and buildings [xxx]; [2] Includes engineering design, supervision, management overheads[xxxiii]; [3]Includes commission, contingency, contractor’s fees and interest during commissioning [xxxiii]; [4]Estimate based on data from Bartel et al. [xxxiv];[5] Adopted from Bridgewater et al.[xxxiii]; [6]Adopted parameters(lumped or direct values) for fluid or simple chemical processing plants from Peters and Timmerhaus [xxx]		

Table 4: Summary of assumptions in estimating the Total Capital Investments (TCI)

The TPC comprises the Direct Cost- DC (raw materials, labor, utilities, maintenance & repairs, operating supplies), Fixed Charges-FC (Plant depreciation, taxes, insurance), General Expenses- GE (administration expenses, interests on loans) and Overhead Cost-OC (Non-manufacturing costs such labor burden, safety and health provision)[xxx].Table 5 summarises the costs of major utilities and raw materials considered in the estimation of the DC for the Rec-UO-to-DF and DF-power facilities. Power tariffs in Ghana differ based on the consumption rate, and the end use, which ranges between $0.08-0.24/kWh for residential end use, and $0.24-0.41/kWh for commercial/industrial end use [xxxv].The power price considered in the economic assessment for the Rec-UO-to-DF process was $0.22/kWh, which was based on commercial end usetariff of $0.22/kWh for a consumption rate between 300-600 kWh [xxxv]. On the other hand, the considered power prices for the DF-power process ranged between $0.08-0.41/kWh- based on the assumption the generated power could be sold to residential or commercial facilities. Labor costs were obtained from salary data or projected based on minimum wage of$2.01[xxxvi]. Plant maintenance cost and OC were specified as 2.5% and 2.0% of the TFC, respectively [xxxiii]. Zero salvage value and linear depreciation were presumed in the estimation of plant devaluations. Corporate tax rate of 25% of net income[xxxvii] was also considered.

Process Inputs	Prices
Used Oil (UO)	$0.158/l[1]
Diesel fuel	$0.79/l[2]
98 wt.% H_2SO_4	$0.64/l[3]
NaOH pellets	$0.38/kg[3]
Activated clay (Bentonite)	$0.54/kg[3]
Electricity	$0.08-0.41/kWh [4]

[1] This was the initial assumed price for setting up the economic model, which was the average from an unverified advertisement on procuring UO at prices of $0.135-0.18/l (Available online: http://ghanaoffer.com/classifieds/show-ad/113/we-looking-for-used-engine-oil/accra/west-africa/ghana/business-opportunities/); [2] Retail price from Oil Marketing Companies (OMCs) as at July, 2016 (Available online: http://www.ghana.gov.gh/index.php/media-center/news/166-omcs-reduces-fuel-pricesdrastically);[3]Average prices provided by local suppliers; [4]Approved tariff ranges by the Public Utility Regulations Commission (PURC), comprising $0.08-0.24/kWh for residential end use, and $0.24-0.41/kWh for commercial/industrial end use [xxxv].

Table 5: Costs of major process inputs (raw materials & utilities) considered in this study

In the DCFROR analysis, a private investment with a financing structure of 50% equity and 50% loan was assumed. Based on prevailing nominal interest rate of 26% [xxxviii], the investor’s expected returns was specified as 40%. Hence, the considered discount rate in this study was the weighted (based on the interest rates and financing structure) nominal discount rate of 33%.Thus, an IRR of 33% was the set condition of economic viability in this study. Also, to resolve impacts of the nominal discount rate on the real value monetary projections, an annual inflation rate of 16% [xxxviii] was considered in the future cash flow projections [xxxiii]. A plant life of 20 years was considered for the DF-power plant [xxxiv], while that of the Rec-UO-to-DF was specified as 15 years due to the severe corrosive nature of the process chemicals and UO [xi]. Project implementation period of 1 year was assumed for the Rec-UO-to-DF and DF-power plants.

3. Results and Discussions

3.1. Financial Demands of the Rec-UO-to-DF and the DF-power Processes

3.1.1. Capital Investment Demands

Fig. 4 shows the breakdown of the estimated Total Capital Investment (TCI)for the studied Rec-UO-to-DF and DF-power generation processes. The estimated TCI for the Rec-UO-to-DF and DF-power were approximately $455000 and $736000 respectively. Specific TCIs, which is the TCI per unit feed or product, were found to be $38/l UO per day and $588/kW for the Rec-UO-to-DF and DF-power plants, respectively. Estimated DPCs were approximately 40% and 48% of the TCI for the Rec-UO-to-DF and DF-power processes respectively. For both processes (Rec-UO-to-DF and DF-power), the estimated working capital (WC) was ~ 30% of their respective TPCs.

With regards to the Rec UO-to-DF process, literature on investments was unavailable for comparison. Hence available data on refinery of crude was used as a basis. According to Gary and Handwerk [xxxix], specific TFC for crude oil refineries is typically around $228/l crude oil per day (adjusted value of reported $157/l per day), with a margin of ±50% in actual practice. Although, the Rec-UO-to-DF process is not as complex as crude oil refining, its specific TCI of $38/l UO per day shows it is relatively less capital intensive when compared to the $228/l per day for crude oil refining. Local oil refineries, with objective of producing diesel as main product, could consider investments in Rec-UO-to-DF, as a means to augment the DF production at a lesser investment demand. Likewise, investment in Rec-UO-to-DF by local investors with relatively minimal capital also seems probable.

For the DF-power plant, the obtained specific TCI of $588/kW compares fairly with reported specific TCI, adjusted value of $453/kW, for similar diesel generator power plants in the USA [xxxiv]. Reports suggest the specific TCI for diesel generator power plants is highly dependent on the plant capacity [xxiv]. Thus variation in the considered plant capacities could have contributed to the difference in specific TCIs [xxiv], as the referred study’s estimate was average for 1-10 MW plants, as compared to the 1.25 MW considered in this study.

The estimated DPC for the DF-power was ~2 folds the estimated DPC for the Rec-UO-to-DF process (see Fig. 4). This could be justified by the high purchase and freight costs of the diesel genset [xxxiv], compared to the relatively accessible and inexpensive equipment for the Rec-UO-to-DF process [xi, xvii], as both referred equipment accounted for ~75% of their respective DPCs (see details in Table 4). Also, the high TCI for the DF-power plant when compared to the TCI for the Rec-UO-to-DF process (~1.6 folds high), suggests a potentially high investment challenge for the power generation as compared to the recycling of UO to DF. Creation of governmental incentives to promote private investment in DF-power generation could target avenues of minimizing investment costs for the power generation section, such as implementation of policies on import tax exemption for diesel gensets or tax rebate for DF-power processes.

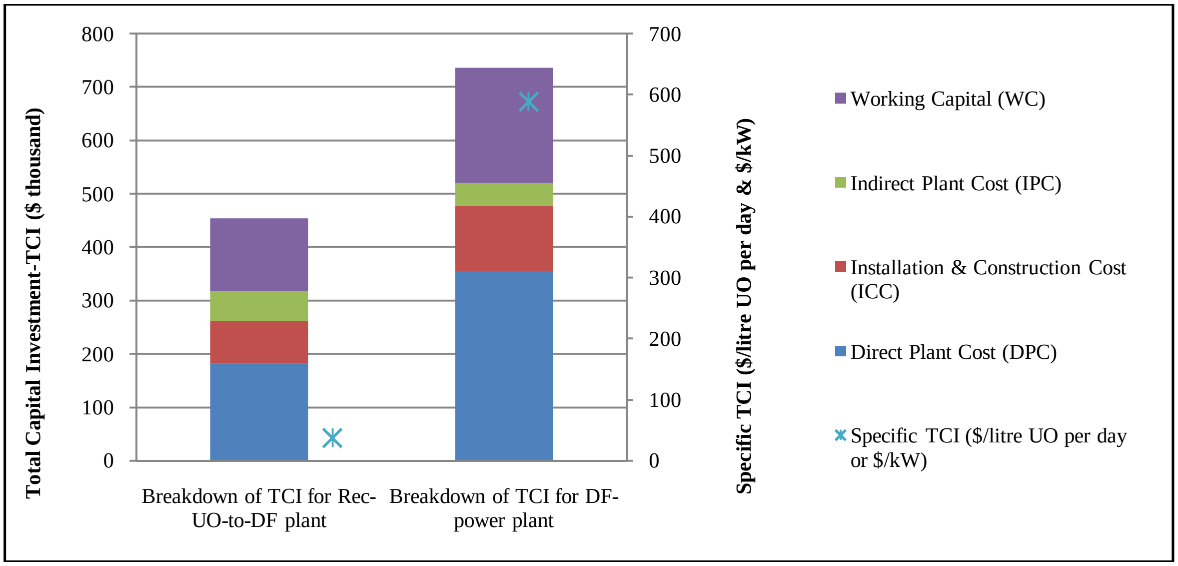

Figure 4: Breakdown of Total Capital Investment (TCI) for the studied processes

3.1.2. Production Cost Demands

The breakdown of the Total Production Cost (TPC) for the Rec-UO-to-DF and DF-power plants are shown in Fig. 5.Estimated annual TPCs for the Rec-UO-to-DF and DF-power are \$1.64 million and \$2.60 million respectively. Specific TPC (TPC per unit feed or product) of \$0.65/l DF and \$0.29/kWh were obtained for the Rec-UO-to-DF and DF-power respectively.

In relation to the Rec-UO-to-DF process, the UO (raw material) and the operating supplies (NaOH pellets, H_2SO_4solution, and activated clay) were the major contributing components of the TPC, contributing nearly 35% and 48% of the TPC respectively. The UO contribution of 35% of TPC corresponds to the assumed initial UO price of \$0.153/l (see Table 5). For chemical processes, raw materials contribution to production cost are typically within ranges of 10 to 50% of TPC [xxx]. Thus, the estimated raw material cost contribution of 35% of TPC (at the initially assumed UO price of \$0.153/l) for this study seems probable. Also, the operating supplies, comprising NaOH pellets, 98wt. % H_2SO_4, and activated clay, are usually imported [xl]. The additional freight cost and import taxes, which reflects in retail cost, could explain the high impacts of cost of supplies on the operational cost for the Rec-UO-to-DF process.

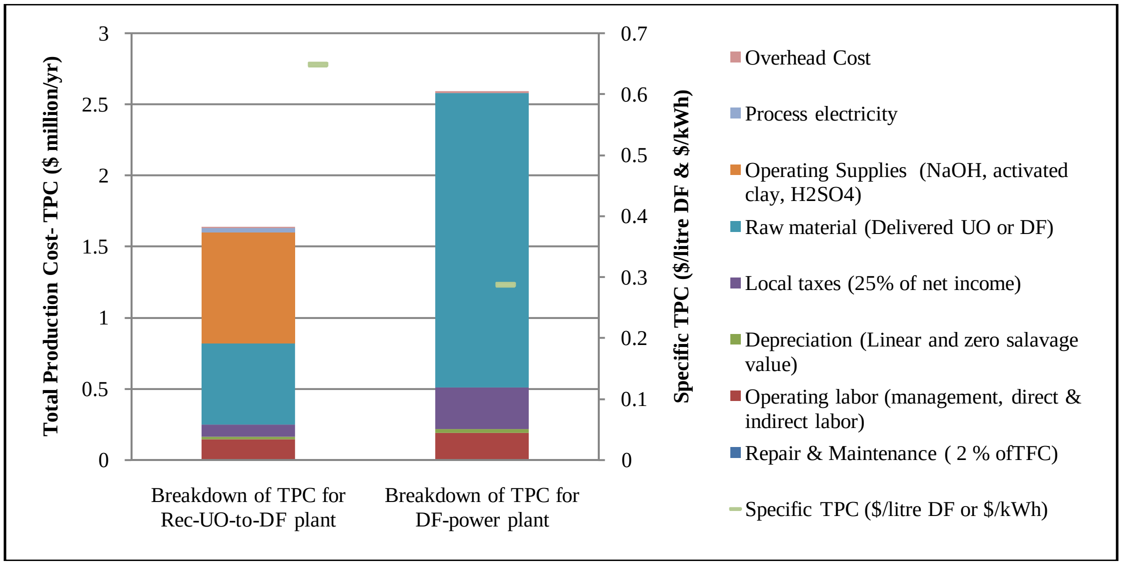

Figure 5: Breakdown of Total Production Costs (TPC) for the studied processes

For the DF-power process, the DF (raw material) accounted for ~80% of the TPC. The fixed charges, comprising the costs of plant depreciation and local taxes [xxx], accounted for 12.3% of the TPC. In a related study, fuel costs and fixed charges for a light crude oil fueled power generation plant in Ghana (in 2008) were approximately 71% and 11.2% of the TPC respectively [xli]. The breakdown of the estimated TPC therefore compares well with the findings of PSEC [xli]. The higher fuel cost contribution to TPC for this study, as compared to the findings by PSEC [xli] (higher by 9%), can be attributed to variations in the process fuel and the prices thereof, as well as differences in economic conditions for the year 2008- the study of PSEC [xli] and year 2016- this study [vii]. Also, typical specific TPC for thermal power generation in Ghana reportedly ranged between $0.06/kWh and $0.1/kWh- adjusted 2016 values [xlii]. The wide margin (margin of $0.19/kWh) between the reported and the found specific TPC in this study could be mainly due to differences in fuel prices, as fuel cost accounts for the largest share (80%) of the TPC [xli, xlii]. The high contribution of fuel cost to the TPC (80%) implies the production cost for DF-power generation is highly reliant on the fuel's cost. This finding is further supported by the trend of escalating thermal power generation costs when there is a rise in crude fuel prices [v, xli]. Conclusively, high fluctuations in fuel cost implies high uncertainties in economics for the DF-power process.

3.2. Impacts of Raw Material Pricing on Economics of Rec-UO-to-DF and DF-power Processes

3.2.1. Impacts of UO Pricing on the Economics of the Rec-UO-to-DF process

Fig. 6 shows the responses of Internal Rate of Return (IRR) and DF selling price to changes in the UO price for the Rec-UO-to-DF process. It was shown (Fig. 6) that the DF price and the IRR were linearly related to the UO price.

The Maximum Expected Selling Price of UO(MESP-UO)[i.e. delivered UO price that makes the Rec-UO-to-DF process economically viable (IRR of 33%)when the DF is sold at prevailing diesel price ($0.79/l)] was found to be$0.21/l (see Fig. 6). Purchasing the UO at a price ≥ $0.22/l, while selling the DF product at prevailing diesel price of $0.79/l, results in the Rec-UO-to-DF process to be economically unviable (IRR ≤ 31%). In a report by the Energy Commission (2015), light crude oil prices were projected at $55-60 per barrel for refinery operations. Taking an average price of $57.5 per barrel (~$0.36/l) as a basis, the light crude oil price is ~46% of the prevailing diesel price ($0.79/l). On the other hand, the found MESP-UO ($0.21/l) is 27% of the prevailing DF price. Hence, on the basis of feed to product cost ratio, purchasing the UO at the found MESP-UO still makes the Rec-UO-to-DF process competitive to the processing of crude oilto diesel.

According to Nolan et al. [xliii], some UO recycling companies acquired the UO at a maximum cost of $0.05/l (adjusted 2016 value) from the UO generators in some states in the USA. Also, Chia-Yu [viii] reported landfill disposal of a 55-gallon container of UO mixed with sorbent cost around $150 to $350 in some states. The found MESP-UO ($0.21/l) is ~4 folds the adjusted price ($0.05/l) by Nolan et al. [xliii], which suggests the MESP-UO as relatively high. The well-established and enforced environmental regulations on disposal or reprocessing of UO in the USA [xliv] compels the generators to deliver the UO for a relatively low incentive or in some cases even pay for its disposal. On the other hand, environmental laws on UO disposal are not enforced in Ghana, which promotes the indiscriminate disposal [xii]. It is therefore envisaged that the actual selling price of the UO could be considerably lower than the found MESP-UO ($0.21/l) should environmental regulations regarding UO disposal or recycling be strictly enforced.

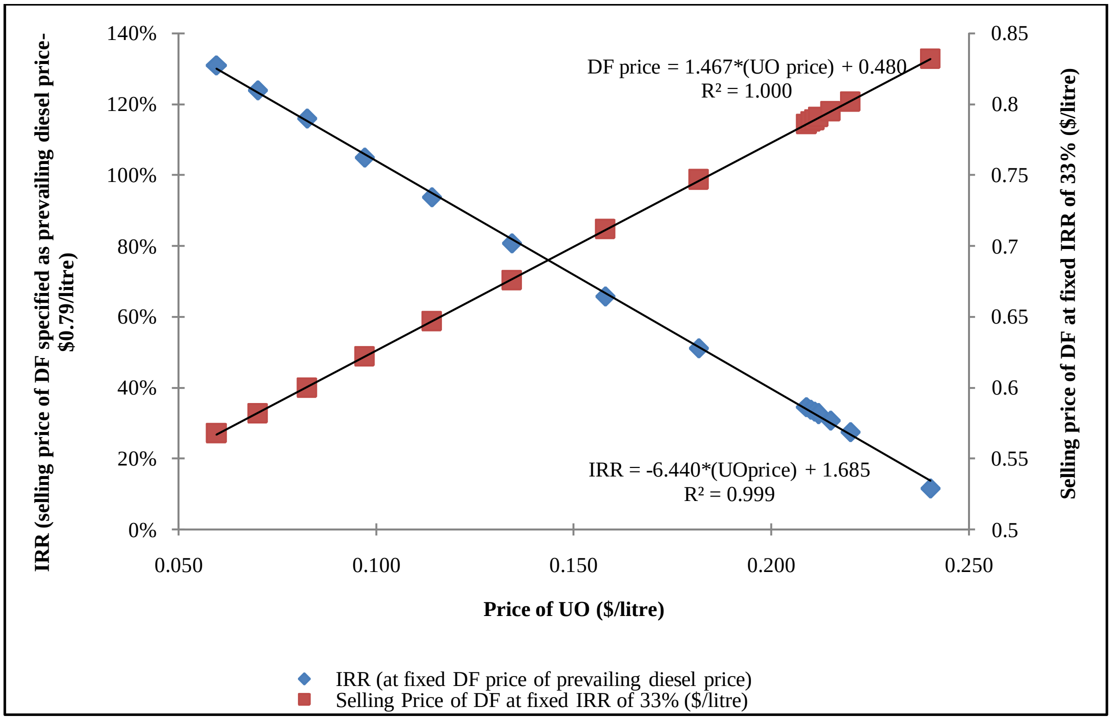

Figure 6: Response of DF price and IRR to changes in UO prices for the Rec-UO-to-DF process

In addition, a 10% increase in UO price results in a 3.2% increase in the DF price [estimated from the linear correlation: DF price =1.467*(UO price) + 0.48; see Fig. 6]. Variation in the UO price therefore appears to have a relatively minor impact on the DF price. However, in the context of the local economic conditions, an increase in DF price by 3.2%, which translates to increase in the price by \$0.025/l, could be economically significant considering the increment (\$0.025/l) is approximately 1.3% of the daily minimum wage (~\$2). The severity of the increment is even more significant in scenarios of larger fuel consumptions. Relative to the national minimum wage of ~\$2, the found MESP-UO (\$0.21/l) is envisaged as an ample incentive for entrepreneurs to venture into the business of collection and supply of UO to recycling facilities.

3.2.2. Impacts of DF Pricing on the Economics of the DF-power Generation Process

Fig. 7 shows the correlation between the power price and the DF price for the DF-power generation process. It was shown that the DF price correlates linearly with the power price [Power price = 0.29 (DF price) + 0.08; see Fig. 7].Additionally, a 10% increase in DF price results in a 7.5% increase in the power price (estimated using the linear correlation: Power price = 0.29 (DF price) + 0.08; see Fig. 7). Therefore, the DF price is highly influential on the required power price for economic viability of the DF-power process. This is further evident in the fuel cost contributing to ~80% of the TPC for the process (see Fig. 5).

At the prevailing DF price of \$0.79/l, the minimum power price that will ensure economic viability (IRR of 33%) of the process was found at \$0.31/kWh. This power price (\$0.31/kWh) is within the range for grid price for commercial applications (\$0.24-\$0.41/kWh), but ~23% higher than the maximum grid price for residential applications (\$0.08-\$0.24/kWh).Thus, this finding recommends the DF-power generation as most appropriate for commercial applications, with regards to economic viability under the year 2016 economic conditions.

The delivered DF price that ensures economic viability (IRR of 33%) of the process under condition of selling the generated power at maximum grid prices [termed maximum expected selling price of DF (MESP-DF)], were found to be \$0.55/l and \$1.14/l for residential (maximum price of \$0.24/kWh) and commercial (maximum price of \$0.41/kWh) respectively. Thus, it can be inferred that the DF-power is economically viable for commercial applications, considering its MESP-DF (\$1.14/l) is ~1.5 folds the prevailing diesel price (\$0.79/l). On the other hand, application of the DF-power for residential power supply will require reduction in the prevailing DF price (\$0.79/l) by ~31%. Purchasing the DF at the MESP-DF for residential use (\$0.55/l) could however be realized if the DF is sourced from a Rec-UO-to-DF facility that obtains its UO at ≤ \$0.05/l [projected from the correlation: DF price =1.467*(UO price) + 0.48; Fig. 6]. Interventions to improve the economics of DF-power in Ghana should therefore develop and enforce the environmental laws on UO disposal, which will compel UO generators to supply the UO at lesser cost for recycling to DF. This will further help prohibit the indiscriminate disposal of UO and as a result reduce the associated health and environmental detriments.

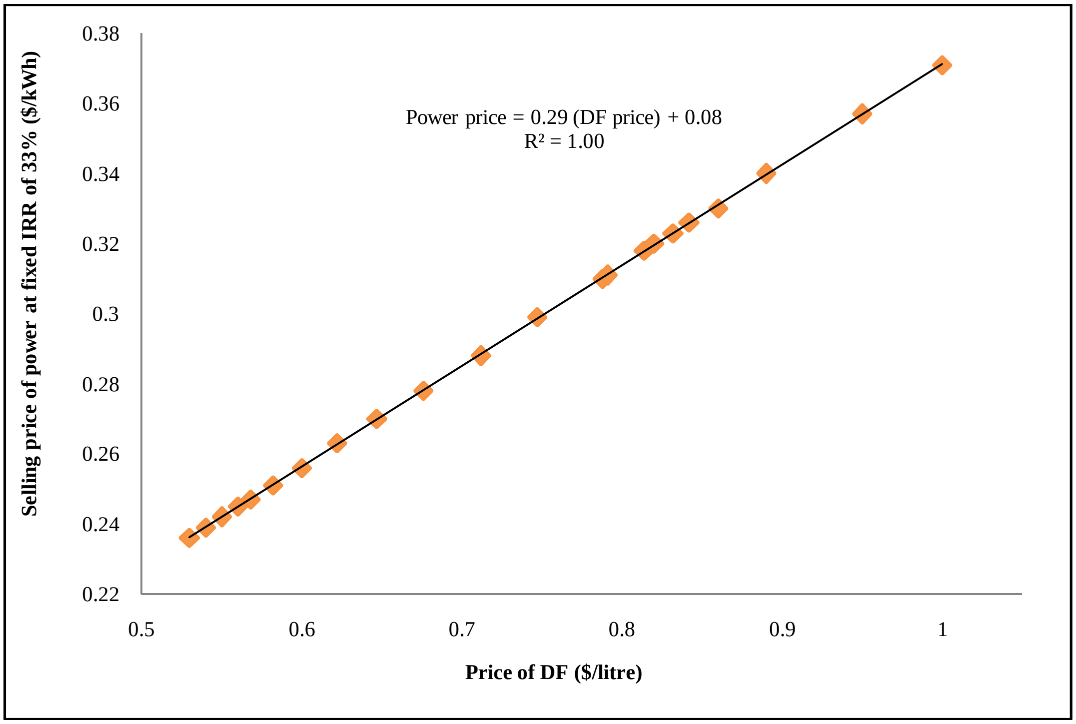

Figure 7: Power price vs Diesel fuel (DF) price for the DF-power generation process

4. Conclusions

It is projected that over 12.5 MW of power could be produced if all the UO generated in Ghana is recycled to DF for purposes of DF-power, as the study's basis of 1.25 MW corresponds to utilizing only 10% of estimated UO generated.

Under condition of selling the produced DF at prevailing diesel price (\$0.79/l), UO price of \$0.21/lor less is required for economic viability of Rec-UO-to-DF. Considering the daily minimum wage of \$2, the found MESP-UO (\$0.21/l) is deemed appreciable for locals to undertake collection and supply of UO to recycling facilities. Recycling of UO to DF therefore provides opportunity for job creation, thus contribute to socio-economic development.

Economics of DF-power generation is significantly reliant on the DF price, which accounts for nearly 80% of the TPC. Fluctuations in fuel prices therefore creates an avenue of high uncertainties in the economics of the DF-power process. The use of conventional diesel (at \$0.79/l) for power generation requires a minimum power price of (\$0.31/kWh) for the process to be economically viable, thus limiting conventional diesel based power generation to commercial power usage (price of \$0.24-0.41/kWh).Economic viability (IRR of 33%) of DF-power generation will require DF prices of not more than \$0.55/l and \$1.14/l for residential and commercial uses, respectively. The extreme scenario of DF price of \$0.55/l (31% less than prevailing diesel price) for DF-power to be applicable to residential tariffs could be achieved by sourcing DF from a Rec-UO-to-DF facility, which in turn obtains its UO at ≤ \$0.05/l.

Absence of enforcement of environmental regulations on UO management in Ghana contribute to indiscriminate disposal of UO, with associated environmental detriments. Enforcement of environmental laws on handling UO could help lower the anticipated price of UO, which will promote its recycling for purposes of DF for power generation. Such measures could help mitigate the power deficit in Ghana, and consequently contribute to environmental and energy sustainability in Ghana.

4.1. Acknowledgement

The author wishes to express his gratitude to Stable Corps Co. Ltd. for the financial assistance to carry out this study. Much appreciation also goes to Dr. Simiyu of Great Lakes University of Kisumu, Kenya, for reviewing an initial version of the manuscript.

4.2. Highlights

- UO based diesel in Ghana is competitive to conventional diesel at UO prices of ≤ \$0.21/l
- Profitability of DF-power is highly reliant on DF price, reflected as 80% of TPC
- DF-power is a promising solution to mitigate shortfalls in power demand

4.3. Abbreviations

DF, diesel fuel; DF-power, diesel fuel based power generation; IRR, internal rate of return; MESP-DF, maximum expected selling price of diesel fuel; MESP-UO, maximum expected selling price of used oil; Rec-UO-to-DF, recycling of used oil to diesel fuel; TCI, total capital investment; TPC, total production cost; UO, used oil; Wt. %, percentage by weight

5. References

i. Brew-Hammond, A., Kemausuor, F. “Energy for all in Africa - to be or not to be?!”. Curr Opin Environ Sustain 2009; 1:83–8.

ii. IEA- International Energy Agency. Africa Energy Outlook: A focus on energy prospects in sub-Saharan Africa. World energy outlook special report, 2014. Retrieved 18th September, 2016 from: https://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf

iii. WEO- World Energy Outlook. World Energy Outlook 2014 Factsheet: Energy in sub-Saharan Africa Today, 2014. Retrieved 8th October, 2016 from:https://www.iea.org/media/news/2014/press/141013_WEO_Africa_Energy_OutlookFactsheet1.pdf

iv. Asante F.A., Clottey, E.A. Ghana’s electricity industry, 2007. [Online]. Available at: http://www.esi-africa.com/ghana-s-electricity-industry/. [Accessed 3 August 2016]

v. Eshun, M.E., Amoako-Tuffour, J. A review of the trends in Ghana’s power sector. Energy, Sustainability and Society 2016, 5

vi. Amoako-Tuffour, J., Asamoah, J. “Thinking Big” and reforming Ghana’s energy Sector. Report submitted to the African Center for Economic Transformation (ACET), February, 2015.

vii. Energy Commission. Energy (Supply And Demand) Outlook for Ghana, April 2015. Retrieved 5th November, 2016 from: http://energycom.gov.gh/files/Energy%20Outlook%20for%20Ghana%20-%202015.pdf

viii. Chia-Yu, Y. The feasibility studies on sonochemical processes for treating used oil: Toxin reduction for eliminating recycle interference. Doctoral dissertation, University of Southern California, 2008.

ix. Chandler, N."Why would I upgrade to a synthetic motor oil?", 2010. [Online] Available at: http://auto.howstuffworks.com/synthetic-motor-oil.htm [Accessed 3 November 2016]

x. Naima, K., Liazid, A. Waste oils as alternative fuel for diesel engine: A review. J. Pet. Technol. Altern. Fuels, 2013, Vol. 4(3), pp. 30-43. Available online at http://www.academicjournals.org/JPTAFDOI: 10.5897/JPTAF12.026

xi. Hayalu, A. Recycling of used lubricating oil using acid-Clay treatment process. Masters dissertation, Addis Ababa University, 2014.

xii. Mensah-Brown, H. Re-refining and recycling of used lubricating oil: an option for foreign exchange and natural resource conservation in Ghana. ARPN Journal of Engineering and Applied Sciences, 2015, Vol. 10, No. 2

xiii. Beg, R.A., Sarker, M.R.I., Riaz Pervez, Md. Production of diesel fuel from used engine oil. International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS, 2010, Vol. 10, No. 02

xiv. Hewstone, R. K. Health, safety and environmental aspects of used crankcase lubricating oils. Science of the total environment, 1994, 156(3), 255-268.

xv. Utsev, J. T., Aho, M. I., Uungwa, S. J. Lube oil recycling: environmental and economic implications. Energy Science and Technology, 2013, 6(1), 73-78.

xvi. Wyszkowska, J., Kucharski, J., Jastrzębska, E., Hłasko, A. The biological properties of soil as influenced by chromium contamination. Polish Journal of Environmental Studies (2001) 10: 37– 42.

xvii. Nwachukwu, M.A., Alinnor, J.A., Feng, H. Review and assessment of mechanic village potentials for small scale used engine oil recycling business. African Journal of Environmental Science and Technology, 2012, Vol. 6(12), pp. 464-475

xviii. Chow, J. C., Watson, J. G. Health effect of fine particulate air pollution: lines that connect. J. Air and Waste Management Association (2006), 56, 1368-1380.

xix. [19] Abu-Elella, R., Ossman, M. E., Farouq R., Abd-Elfatah, M. Used motor oil treatment: turning waste oil into valuable products. International Journal of Chemical and Biochemical Sciences, 2015, 7p. 57-67.

xx. Udonne, J.D. A comparative study of recycling of used lubrication oils using distillation, acid and activated charcoal with clay methods. Journal of Petroleum and Gas Engineering2011, 2(2), pp.12-19.

xxi. Emam, E.A., Shoaib, A.M. Re-refining of used lube oil, II-by solvent/clay and acid/clay-percolation processes. ARPN Journal of Science and Technology, 2012, 2(11), pp.1034-1041.

xxii. Olugboji, O.A., Ogunwole, O.A. Use of spent engine oil. Technical report. AU J.T., 2008, 12(1): 67-71

xxiii. Mynin, V. N., Smirnova, E. B., Katsereva, O. V., Komyagin, E. A., Terpugov, G. V., Smirnov, B. N. Treatment and regeneration of used lube oils with inorganic membranes. Chemistry and Technology of Fuels and Oils, 2004, Vol. 40, No. 5

xxiv. NREL- National Renewable Energy Laboratory. Power technologies energy data book. Fourth edition. Technical report NREL/TP-620-39728, August, 2006.

xxv. Wolfgang, R. Fundamental principles of generators for information technology. White Paper #93, American Power Conversion, 2004.

xxvi. Dewadasa, M., Ghosh, A., Ledwich, G. Dynamic response of distributed generators in a hybrid microgrid. In IEEE Power Engineering General Meeting (IEEE PES 2011), 24-28 July 2011, Detroit.

xxvii. Diesel service and supply. 2016. Retrieved 8th November, 2016 from:
http://www.dieselserviceandsupply.com/temp/Fuel_Consumption_Chart.pdf

xxviii. Tan, E.C.D, Marker, T.L., Roberts, M.J. Direct production of gasoline and diesel fuels from biomass via integrated hydropyrolysis and hydro conversion process- a techno-economic analysis. Environmental Progress & Sustainable Energy, 2013. Vol.33, No.2. DOI 10.1002/ep

xxix. BoG- Bank of Ghana. 2016. [Online]. Available at: http://www.bog.gov.gh/markets/daily-interbank-fx-rates [Accessed 15 November 2016]

xxx. Peters, M., Timmerhaus, K. Plant Design and Economics for Chemical Engineers. 5th Edition. New York: McGraw-Hill, 2003.

xxxi. [Online] Available at: http://www.matche.com/equipcost/ [Accessed 8 November 2016]

xxxii. [Online] Available at: http://www.machinerytrader.com/listings/construction-equipment/for-sale/list/category/1039/generator-sets?Manu=BALDOR [Accessed 4 November 2016]

xxxiii. Bridgwater, A.V., Toft, A.J., Brammer, J.G. A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion. Renewable and Sustainable Energy Reviews, 2002, 6:181–248.

xxxiv. Bartel, T., Butz, L., Butz, T., Dimberio, T., Stroess, W. Costs of utility distributed generators, 1-10 MW: twenty-four case studies. EPRI, Palo Alto, CA, and Cooperative Research Network, Arlington, VA: 2003. 1007760.

xxxv. PURC- Public Utility Regulations Commission. 2016. PURC Publication of electricity tariff. Retrieved 5th June, 2016 from: http://www.purc.com.gh/purc/node/7470

xxxvi. [Online] Available at: http://www.mywage.org/ghana/home/salary/minimum-wages [Accessed 11 November 2016]

xxxvii. GRA- Ghana Revevenue Authority. 2014. [Online]. Available at: http://www.gra.gov.gh/index.php/tax-information/income-tax [Accessed 20 July 2016]

xxxviii. BoG- Bank of Ghana. 2016. [Online]. Available online at: http://www.bog.gov.gh/ [Accessed 10 September 2016]

xxxix. Gary, J.H., Handwerk, G.E. Petroleum refining technology and economics. 4th Edition., New York: Marcel Dekker, Inc., 2001

xl. [Online] Available at: http://importer.tradekey.com/ghana/chemicals.htm [Accessed 9 November 2016]

xli. PSEC- Power Systems Energy Consulting. Ghana wholesale power reliability assessments. Report prepared in collaboration with GRIDCO, March, 2010.

xlii. ISSER. Guide to electric power in Ghana. Resource Center for Energy Economics and Regulation. Institute of Statistical, Social and Economic Research, University of Ghana, Legon, 2005.

xliii. Nolan, J.J., Harris, C., Cavanaugh, P.O. Used oil: Disposal options, management practices and potential liability. 3rd ed. Government Institutes Inc., Rockville, MD., 1990.

xliv. U.S. EPA- Environmental Protection Agency. Environmental regulations and technology: managing used motor oil. EPA/625/R-94/010, Office of Research and Development, Washington, DC, December, 1994.