Analysis of clean coal technology in Nigeria for energy generation

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Abstract

An analysis of clean coal technologies for the recovery of energy from Nigerian coals was carried out. The coal mines studied are Onyeama, Ogwashi, Ezimo, Inyi, Amasiodo, Okaba, Lafia-Obi, Owukpa Owukpa, Ogboyoga and Okpara. The estimated reserves of the ten coal deposit amount to 2.1 Gt, which is about 84 % of the total coal reserves of the country 2.5 Gt of coal Nigeria. The key clean coal technologies studied are Ultra-Supercritical Combustion (USC), Supercritical-Fluidised Bed Combustion (FBC), Integrated Gasification Combined Cycle (IGCC) and Coal bed Methane (CBM) and the results were compared with conventional subcritical pulverised fuel combustion (PF). The total potential energy recovery from these technologies are: PF 5800 TWh, FBC 7250 TWh, IGCC 7618 TWh, and USC 8519 TWh. This indicates an increase of about 31% in the total electricity generation if USC technology is used instead of the conventional sub-critical PF technology. About 39% of the total electricity generation of 8519 TWh from USC could come from Amasiodo coal deposit, making it the highest contributor to the total power generation. Inyi coal had a contribution of ~ 1.5% making it the lowest contributor. The lowest CO_2 emission factor was from Onyeama coal and was reduced from 1.0 kg CO_2/kWh in PF to 0.68 kg CO_2/kWh in USC. Oghwashi coal had the lowest energy and highest emission factor. There will be a need for the coal upgrading/beneficiation for optimal energy recovery.

Key Words: Clean Coal Technologies , Nigeria, coal, Energy recovery, Emission factors,

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1 Introduction

Nigeria has estimated coal reserves of 2.5 Gt [1]. About 90% of the coal reserves are sub-bituminous and bituminous coals with the remainder being of lignite rank [2]. These coal reserves are located in the Lower, Middle and Upper Benue Trough. Lignite and Sub-bituminous coals are mainly found in the Lower and Upper Trough and high–volatile bituminous coals in the Middle Trough [3]. Some of the notable coal mines in the Lower Trough include Onyeama and Okaba and Lafia-Obi for the Middle Trough. All in all, there are about 23 coal mines in Nigeria [1], some of which are currently not in operation[4].

Previously, coal was mainly used to power trains and also for electricity generation [5]. The peak of production and consumption was in the late 1950s when the production was about 800,000 t per year, the domestic consumption was about 700,000 t per year and the remainder was exported [5]. The Nigeria Railway Corporation consumed about 50% and the Electricity Corporation of Nigeria (ECN) consumed about 20% of the total coal produced. The remaining local coal production was consumed by the shipping industry and government agencies and other users [5].

The replacement of coal with diesel in the powering of the trains and with gas and hydro for electricity generation led to a drastic drop in coal production and utilisation. This led to the closure of the two coal power stations in Nigeria, namely the Oji coal power station in Enugu and Ijora power station in Lagos [5-6]. The present production and utilisation of coal in Nigeria is very low [7-8]. Coal is mainly used as a heat source in cement production. Other industries that use coal as heat source are the brick factories and bakeries [9].

The present electricity generation in Nigeria fluctuates between 2687 MW and 4200 MW while the estimated peak demand is 12800 MW[10]. This results in a 67-79% electricity deficit. The government plans to increase its generating capacity to 40000 MW in 2020. According to the Nigerian government power growth plan, coal is projected to contribute about 6% of the 40 GW target in 2020 [11]. Some of the planned coal power plants will be in Enugu (1600 MW), Kogi (1000 MW) and Benue (1200 MW) [4, 11]. The coal sources for the planned power stations are located at Enugu (Ezinmo, Inyi), Kogi (Okaba, Ogboyoga), and Benue (Orukpa) [4].

The technology to be applied in the proposed power plants has not been finalised. There is a need to use technologies that promote high efficiency. According to a report by the World Coal

Associaion (WCA) on accelerating coal power efficiency, a 1% increase in coal-fired plant efficiency can lead to 2-3% decrease in emissions [12]. This is illustrated in Figure 1.

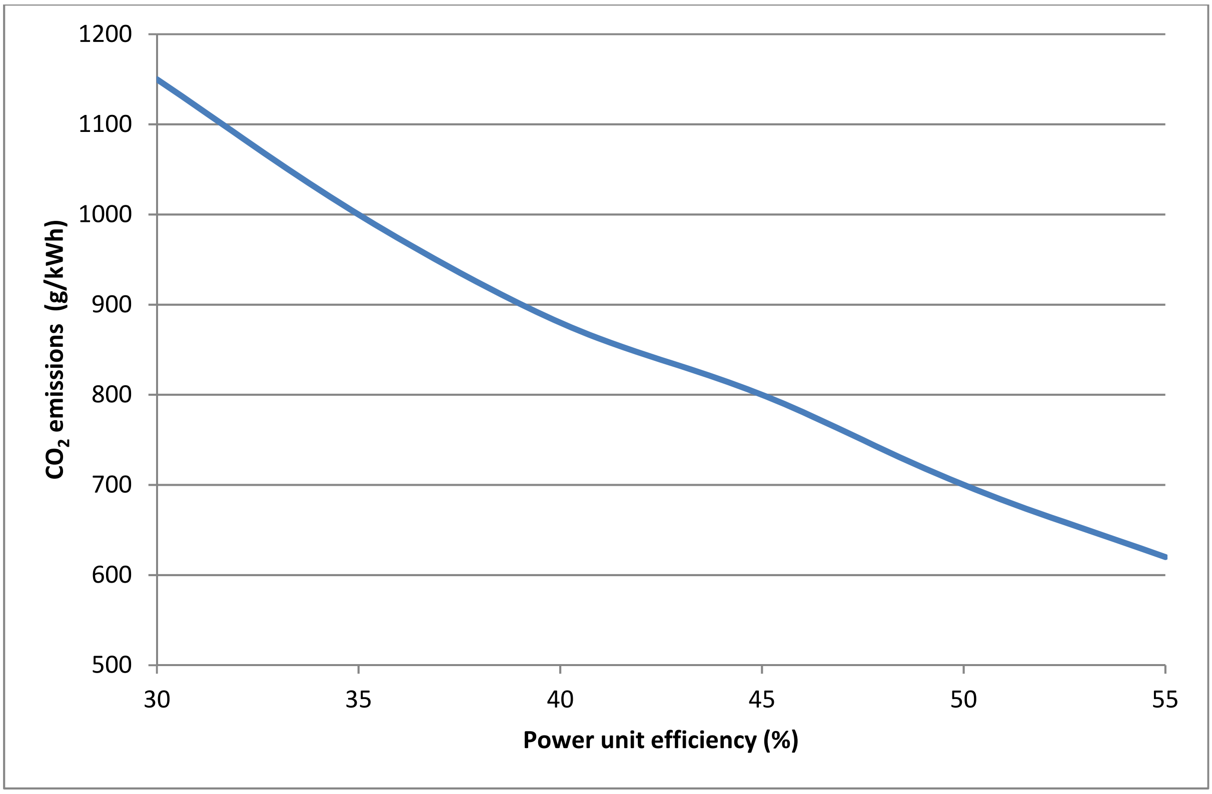

Figure 1: Reduction of emissions through efficiency improvements [13-14].

Higher efficiency and low emission(HELE) coal plants are key components of clean coal technologies (CCT) [15-16]. CCT are technologies that allow the power generation industry to cleanly and efficiently use coal as an energy source [16]. Some of the notable clean coal technologies are Ultra-Supercritical Pulverised Fuel Combustion (USC), Fluidised Bed Combustion (FBC), Integrated Gasification Combined Cycle (IGCC), and Coal Bed Methane Technology (CBM) [17-19]. These clean coal technologies (USC, IGCC, FBC and CBM) and the conventional Subcritical Pulverised Fuel Technology (PF) can be applied in the recovery of energy from the coal reserves in Nigeria. USC, FBC, IGCC and PF are primarily *ex-situ* technologies that involve the mining of coal followed by combustion or gasification for energy recovery, CBM is an *in-situ* technology that involves the recovery of methane gas from coal seams prior to the mining of the coal. The methane gas can then be used in a gas turbine for electricity generation [20-21]. The recovery of the methane can also help in the mitigation of the emission of the methane in the coal mine and the fire hazards associated with the release of entrapped methane during mining and thereby increasing the safety of the miners [22].

The evaluation of the use of advanced clean coal technologies such as USC, FBC, IGGC and CBM on the recovery of energy and emissions reduction from Nigerian coal reserves has not been carried out in detail.

Sambo [23] reported that about 3,500 MW of electricity can be generated from coal deposits in Orupka and Ezimo coals in Benue State without specifying the type of coal power technology. Chukwu [24] reported that coals from five coal mines (Odagbo, Owukpa, Ezimo, Amansiodo and Inyi) are suitable for power generation using pulverised fuel technology and fluidised bed technology based on their coal properties.

Amoo [25] also reported that Lafia-Obi coal can be used for electricity generation using fluidised bed technology. He evaluated the fluidised bed properties of Lafia-Obi under air and oxy-combustion conditions using a CFD model.

Adeyinka [26] reported on the gasification properties of a Nigeria bituminous coal, but there was no mention of the evaluation of power production through an Integrated Gasification Combined Cycle (IGCC) process for the particular coal.

This study aims to evaluate the coal consumption rate, emission factor and total energy recovery for USC, FBC, IGGC and CBM technologies and compare them with those from a conventional low efficiency subcritical pulverised fuel (PF) for several coals from ten different coal mines in Nigeria, namely Onyeama, Ogwashi, Ezimo, Inyi, Amasiodo, Okaba, Lafia-Obi, Owukpa Owukpa, Ogboyoga and Okpara. The estimated reserves of these coal mines are 2.1Gt, i.e.. about 84% of the total estimated reserves of the 2.5 Gt of coal. The coal mines are open cast (surface mining) and underground [1]. An overview of the mines is presented in Table 1. The proximate and ultimate analyses of the different coals is presented in Table 2 and are obtained from the literature[27-31].

Table 1: Overview of the selected coal mines [1]

Mine	Coal Rank	Estimated Reserves (Million Tonnes)	Depth of Coal (m)	Mining Methods
Onyeama	Sub-bituminous	150	180	Underground
Ogwashi	Lignite	250	15-100	Open Cast and Underground
Ezimo	Sub-bituminous	156	30-45	Open Cast and Underground
Inyi	Sub-bituminous	50	25-78	Open Cast and Underground
Amasiodo	Bituminous	1000	563	Underground
Okaba	Sub-bituminous	250	20-100	Open Cast and Underground
Lafia-Obi	Bituminous	156	80	Underground
Owukpa	Sub-bituminous	75	20-100	Open Cast and Underground
Ogboyoga	Sub-bituminous	427	20-100	Open Cast and Underground
Okpara	Sub-bituminous	100	180	Underground

Table 2 : **Proximate and Ultimate analysis analysis of the coal from the selected mines**

Coal Mines	Moisture %	Volatile Matter %	Ash %	Fixed Carbon %	Calorific Value MJ/kg	C %	H %	N %	S %	O %
Onyeama [26,30]	3.03	35	13.4	48.6	33.3	75.8	5.3	1.9	0.5	16.8
Ogwashi[8]	23.2	27.8	5.2	43.8	16.7	64.3	6.5	1.1	4.3	23.7
Ezimo[23]	7	32	23	38	21	77.4	6.3	1.7	0.8	13.7
Inyi[23]	4	30	30	36	19	74.9	6.4	1.9	0.9	16.1
Amasiodo [23]	5	38	9	48	28	77.8	6.5	1.8	1.1	12.7
Okaba[30]	7.1	46.3	6.1	40.6	30.3	73.7	5.9	1.8	0.5	18
Lafia-Obi [24]	2.9	27.2	18.6	51.3	23.7	82	5.7	2.0	3.0	7.3
Owukpa [23]	12	39	3	46	27	79.6	6.9	1.7	0.7	11.1
Ogboyoga [28]	6.9	30.4	8.63	54.3	32.5	78.9	4.1	1.2	0.6	6.6
Okpara [6,31]	7.5	38.3	8.4	45.4	27.8	79.1	6.1	2.0	0.1	11.5

The potential energy recovery, emission factors and overall efficiency for PF, USC, FBC, IGGC, were evaluated as follows:

The overall efficiency is a function of the technology, thus : PF is 28-32%, USC is 45-47 %, FBC 35-40% and IGCC is between 35- 42% [18]. In this study, we used the maximum value for each of these technologies.

Heat Rate required to produce one 1 kW = 3600 kJ/hr /Overall efficiency……………1

Coal energy generation rate = Heat rate/ Heating value of the coal (HV) MJ/kg………2

Total Energy recovery= Total coal reserves xCoal energy generation rate…………….3

CO_2 Emission factor= Carbon Content x Combustion efficiencyx 44/12x1/HV……4

Combustion efficiency for the different coals was derived from their fuel ratios. A lower fuel ratio would result in a higher combustion efficiency [32]. The combustion efficiency for all the coals was in the range of 0.88- 0.96

For the CBM technology, the total energy recovery is derived by multiplying the volume of methane in the coal mines and the energy density by the volume of Methane. The energy density by volume of Methane is 9.8 kWh/m^3 [33].

The volume of the methane gas in the coal mines was evaluated by Kim correlation [34], and it is expressed as a function of the coal properties such as the fixed carbon, volatile matter, ash yield and moisture. The volume of methane gas in the coal mines is a function of the depth of the coal seam. The volume of methane gas in the coal mines can be calculated by using Equation 6 [19].

$$V_{gas} = \frac{(100 - \%M - \%A)\left(\frac{V_m}{V_d}\right)\left[K_o(0.096h)^{n_o} - 0.014\left(\frac{1.8h}{100}\right) + 25\right]}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots 6$$

V_{gas} is the volume of methane capacity of the mine, h is the depth of the mine, M: moisture, A; ash yield , V_m is the volume of wet coal and V_d is the volume of dry coal. The volume ratio V_m/V_d is the adsorption capacity of the methane gas in the coal mine/seam and is related to moisture of the coal and is given in Equation 7 [19].

$$\frac{V_m}{V_d} = \frac{1}{C_o M + 1} \quad \ldots\ldots\ldots\ldots\ldots\ldots 7$$

C_o is a constant and it is 0.25

$$K_o = 0.8\left(\frac{FC}{VM}\right) + 5.6 \quad \ldots\ldots\ldots\ldots\ldots\ldots 8$$

FC, VM, fixed carbon and volatile matter respectively of the coal.

$$n_o = 0.315 - 0.01\left(\frac{FC}{VM}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots 9$$

The CO_2 sequestration potential from the recovery of methane gas from coal seams is given by equation 10.

$$Q_{CO_2} = (2\,V_{gas})(weight\ of\ coal\ reserves)(\rho_{CO_2}) \quad \text{.......} 10$$

3.0 Results and Discussion

3.1 Energy recovery and emission factor for PF, USC, FBC and IGCC for the different Coal Mines

The coal consumption rate for PF, USC, FBC and IGCC for the different coal mines is presented in Figure 1. The coal consumption rate for PF, USC, FBC and IGCC for the different coal mines was in the range of 0.25-0.8 kg coal/kWh electricity. The coal consumption ratio (kg Coal/kWh) between PF and USC, FBC and IGCC are; 1.45, 1.25 and 1.31, respectively, for all the coals. This indicates that USC would have the highest overall efficiency, followed by IGCC and FBC, while PF would have the lowest overall efficiency. In terms of the ten coal samples studied, Onyeama coal had the highest combustion efficiency in PF, USC, FBC and IGCC, followed by Ogboyoga and Okaba. Okpara, Amasiodo and Owukpa had the third highest combustion efficiency and Ezimo and Lafia-Obi had the fourth highest efficiency. Inyi had the fifth highest overall efficiency and Ogawashi had the lowest combustion efficiency. An interesting observation is that the lowest electricity generation rate for Onyeama which was in PF would still be higher than the highest electricity generation rate for Oghwashi, Inyi, Ezimo and Lafia-Obi coals which was in USC. Secondly, the lowest electricity generation rate for Ogboyoga and Okaba which was in PF would still be higher than the highest electricity generation rate for Oghwashi and Inyi which would be in USC. Lastly, the lowest electricity generation rate for Okapra, Amasiodo and Owukpa which was in PF would still be higher than the highest efficiency for Oghwashi which would be in USC. This indicates that the use of high efficiency technology such as USC, FBC, and IGCC would not be adequate enough for the optimal recovery of energy from Oghwashi coal. There would be a need for the upgrading/beneficiation of the coal for enhanced energy recovery. Presently, it has a high moisture of 23% and low CV of 16.7 MJ/kg.

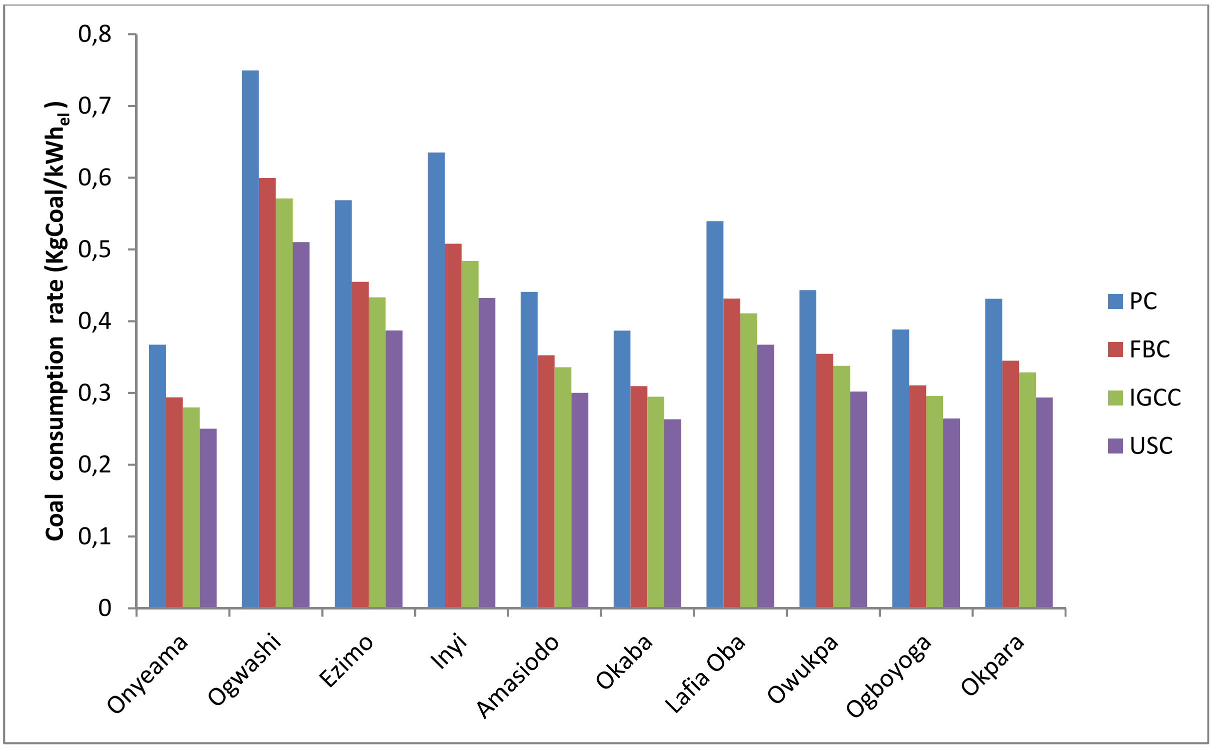

Figure 1: Energy generation rate for the different coal mines

The emission factors for PF, USC, FBC and IGCC for the different coal mines are presented in Figure 2. As expected, PF had the highest emission factor because of its low efficiency and would be in the range of 1-1.8 kg CO_2/kWh for the different coals. USC had the lowest emission factor and was in the range of 0.70-1.2 kg CO_2/kWh. The highest emission factor were in Ogwashi and Inyi coals. The emission factor for these coals reduced from 1.8 Kg CO_2/kWh in PF to 1.2 kg CO_2/kWh in USC. The lowest emission factor was in Onyeama. This was reduced from 1.0 kg CO_2/KWh in PF to 0.70 kg CO_2/kWh. This indicates a 30 % reduction in the emission factor. Similar results were obtained for the other coals. The emission factor was reduced from 1.1 kg CO_2/kWh in PF to 0.71 in USC for Okaba coal, from 1.1 kg CO_2/kWh in PF to 0.76 in USC for Ogboyoga coal, from 1.1 kg CO_2/kWh in PF to 0.71 in USC from 1.3 kg CO_2/kWh in PF to 0.86 in USC for Okpara, Amasido and Owukpa coals. Lastly the emission factor was reduced from 1.6 kg CO_2/kWh in PF to 1.1 in USC for Ezimo and Lafia-Obi coals.

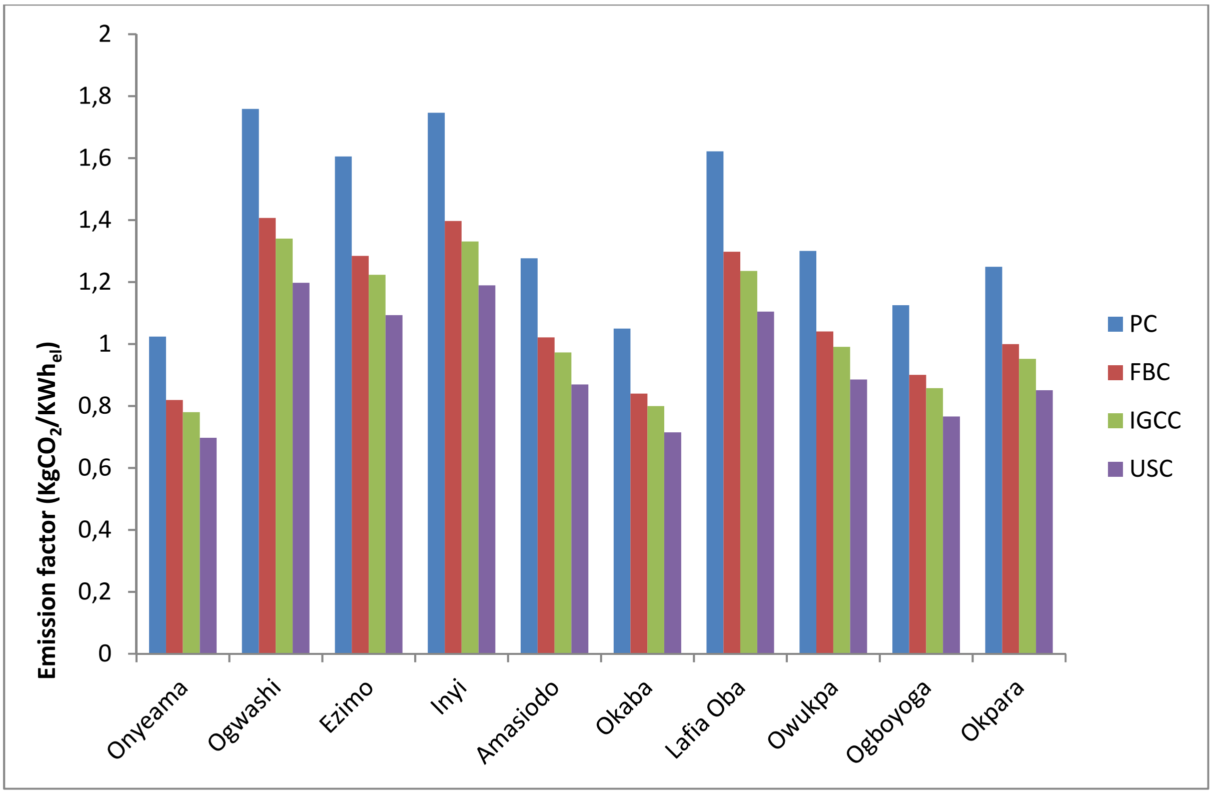

Figure 2 Emission factor for the different coal mines

The total energy recovery for PF, USC, FBC and IGCC for the different coal mines is presented in Figure 3. As expected the highest total energy recovery for each coal was from USC because it had the highest overall efficiency, and the lowest total energy recovery was from PF for all the coals. The estimated total potential energy recovery from the USC plants for the ten coal mines is about 8519TWh and 5800 TWh from the PF plants. This indicates that an increase of ~32% in the total energy recovery if USC is applied instead of PF technology in the coal power plant. It would increase by 20% in FBC and 23 % in IGCC power plants. The total potential energy recovery for the FBC technology for the ten coal mines is 7250 TWh and 7618 TWh for the IGCC technology.

In terms of the coal samples, the highest energy recovery was from Amasiodo coal mines. About 39% of the total electricity generation of 8519TWh from USC, would come from Amasiodo coal mines because it has the highest coal reserve and which is 1Gt. The lowest fraction (1.4%) of the total energy recovery would be from Inyi coal mine and it has the lowest coal reserve of out of the ten coal mines and it is 50 Mt. Although Onyeama coal mine has a lower coal reserve of 150 Mt than Ogwashi coal mine which has 250Mt, it has a higher energy recovery than Ogwashi coal mine. This is obvious as the total energy recovery is a function of the electricity generation rate and the amount of coal reserves.

The contribution of each of the coal mines to the total energy recovery from USC is presented in Figure 4. Similar results were obtained for PF, FBC and IGCC for the coal mines.

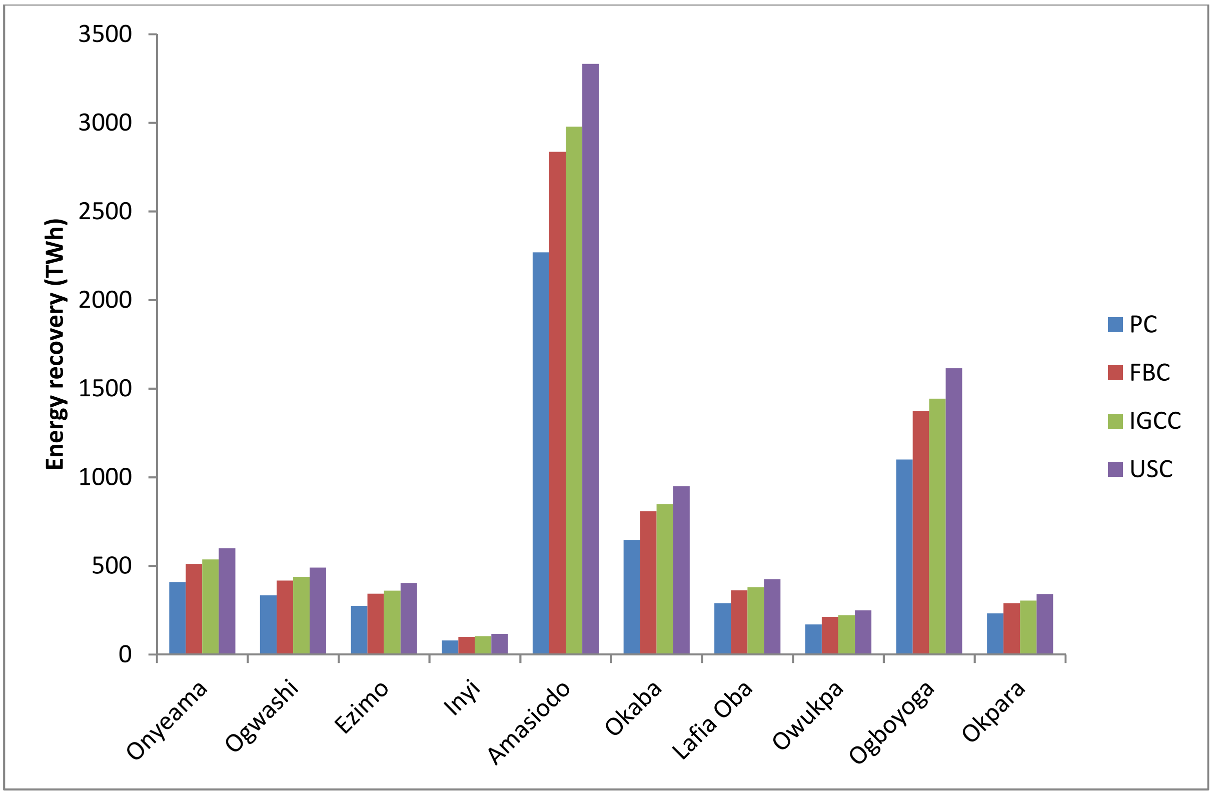

Figure 3 Potential total energy recovery for the different coal minesand the different power generation technologies (PF,FBC,IGCC and USC)

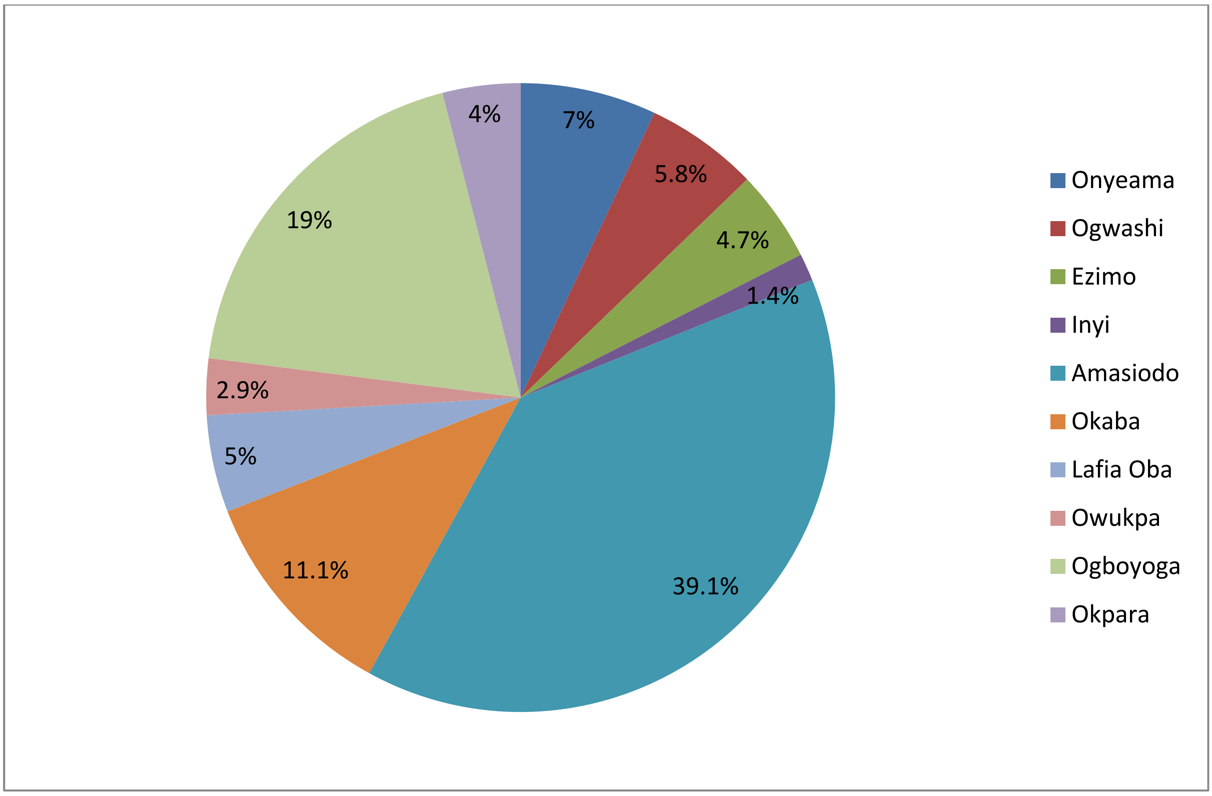

Figure 4 Contribution of each of the coal mines to the potential total energy recovery in applying USC technology

3.2 Energy Recovery from Coal bed Methane Technology

The recovery of methane from coal mines is a key step in the generation of energy in coalbed methane technology. The methane recovered can be used in gas turbines for electricity generation. The methane generation rates for the different coal mines are in the range of 1-8 cm^3/g and (Figure 5). Amasido coal has the highest methane generation rate followed by Onyeama, Lafia-Obi, Okpara, Ogboyoga, Amasiodo, Inyi, Okaba, Owukpa, Ezimo and lastly the Ogwashi coal mine. The difference in the methane generation rate can be attributed to the difference in the coal properties. Prabu and Mallick [19] reported that high ash yield and high moisture in coal can result in low methane gas content. Other properties such as a high fixed carbon and volatile matter in coal can result in high methane gas content. Kim [34] developed a correlation that relates ash yield, moisture, fixed carbon and volatile matter content of coal and the depth of a coal seam to the capacity of the methane gas in the coal seam. The use of this correlation in the estimation of methane gas in coal seams has been reported to be close to experimental values for some coal seams in India [19]. The correlation was used in this study that high methane generation rate such as from Amasido and Onyeama coals have high fixed carbon and volatile matter yield and low ash yield and moisture. While coal samples with low methane generation rate such as Ogwashi and Ezimo have high moisture and ash yield.

The potential energy from Coal Bed Methane (CBM) was evaluated by multiplying the methane generation rate of each coal seam with the coal reserves and the product was multiplied with the methane energy density of 9.8 kWh/m^3 [33]. The results are presented in Figure 6. The Amasiodo coal had the highest potential energy recovery of 81 TWh due to the highest methane generation rate and the largest coal reserves of 1Gt. On the contrary, Inyi had the lowest potential energy recovery of 1.9 TWh because it had the lowest coal reserves of 50 Mt. Owukpa also had a low energy recovery of 2.0 TWh because of its low coal reserves of 75 Mt. On the other hand, Ogwashi had a lower energy recovery of 3.8 TWh even with a relatively high coal reserve of 250 Mt when compared to Onyeama coal with a coal reserve of 150 Mt and a potential energy recovery of 11TWh. The reason is the very low methane generation rate of Ogwashi coal.

The total potential energy recovery from CBM for all the coals is about 142TWh. The results showed that energy recovery from CBM is lower than PF (5800 TWh), FBC (7250 TWh), IGCC (7618 TWh) and USC (8519 TWh).

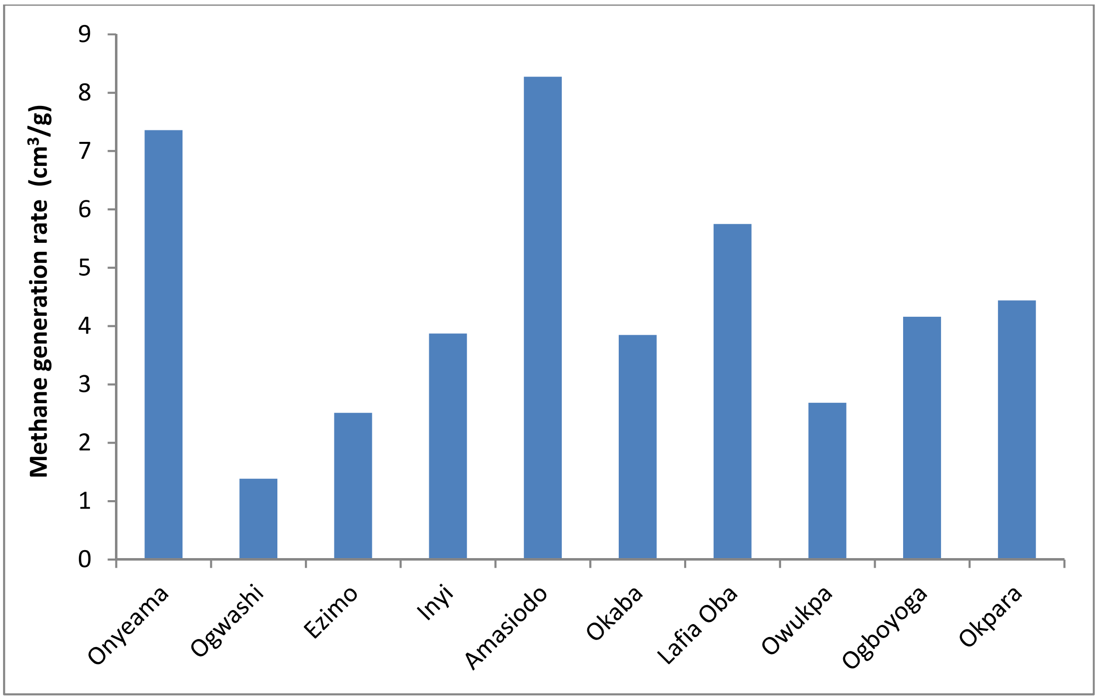

Figure 5: Methane generation rate for the different coal mines

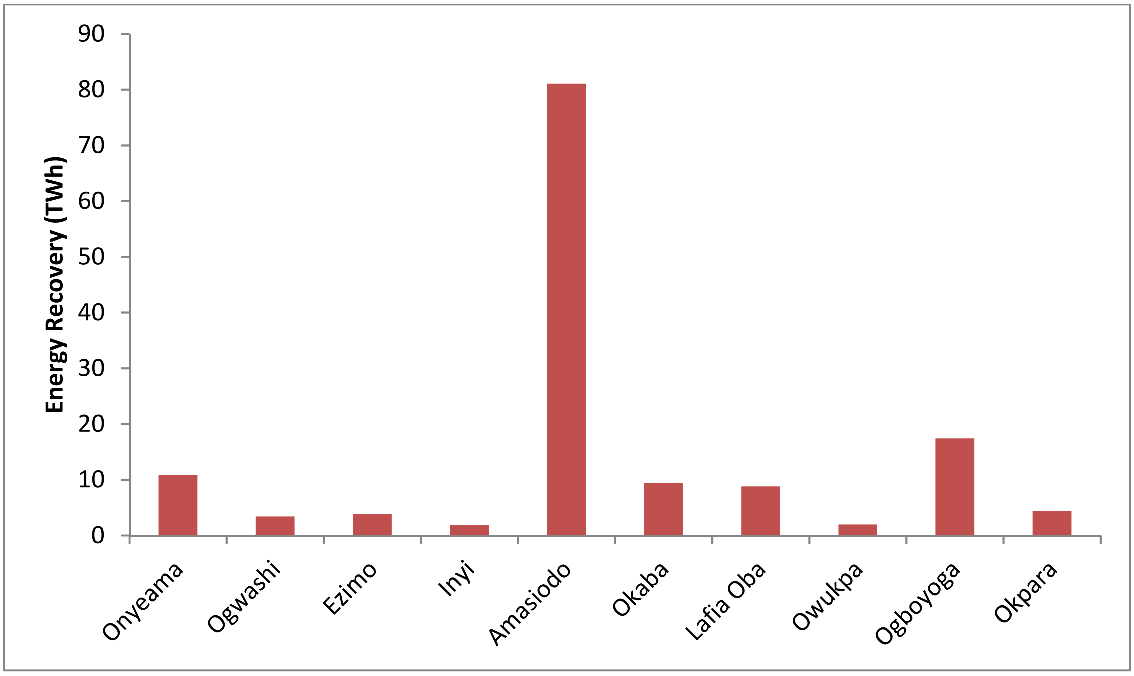

Figure 6: Potential total energy recovery from the different coal mines in CBM

The proportion of the potential total energy recovery from CBM for the different coal mines is presented Figure 7. Similar trends were observed for the *ex-situ* technologies such as PF, USC, FBC and IGCC as well as for CBM an *in-situ* technology. Amasiodo coal provides the highest energy recovery, while Inyi provides the lowest energy recovery. However, the percentage increased from 39% in PF, USC, FBC and IGCC to 58% in CBM for Amasiodo coal while in Inyi coal, it reduced only marginally from 1.4% in PF, USC, FBC and IGCC to 1.3% in the CBM technology. The fraction of the contribution of the Onyeama coal to the total potential energy recovery was now higher than Okaba in CBM when compared to the ; PF, USC, FBC and IGCC technologies. This indicates that the fraction of the contribution of each coal to the total potential energy recovery would be different. It could either be higher in *ex-situ* technologies (PF, USC, FBC and IGCC) or lower in *in-situ* technologies (CBM) and the same in both.

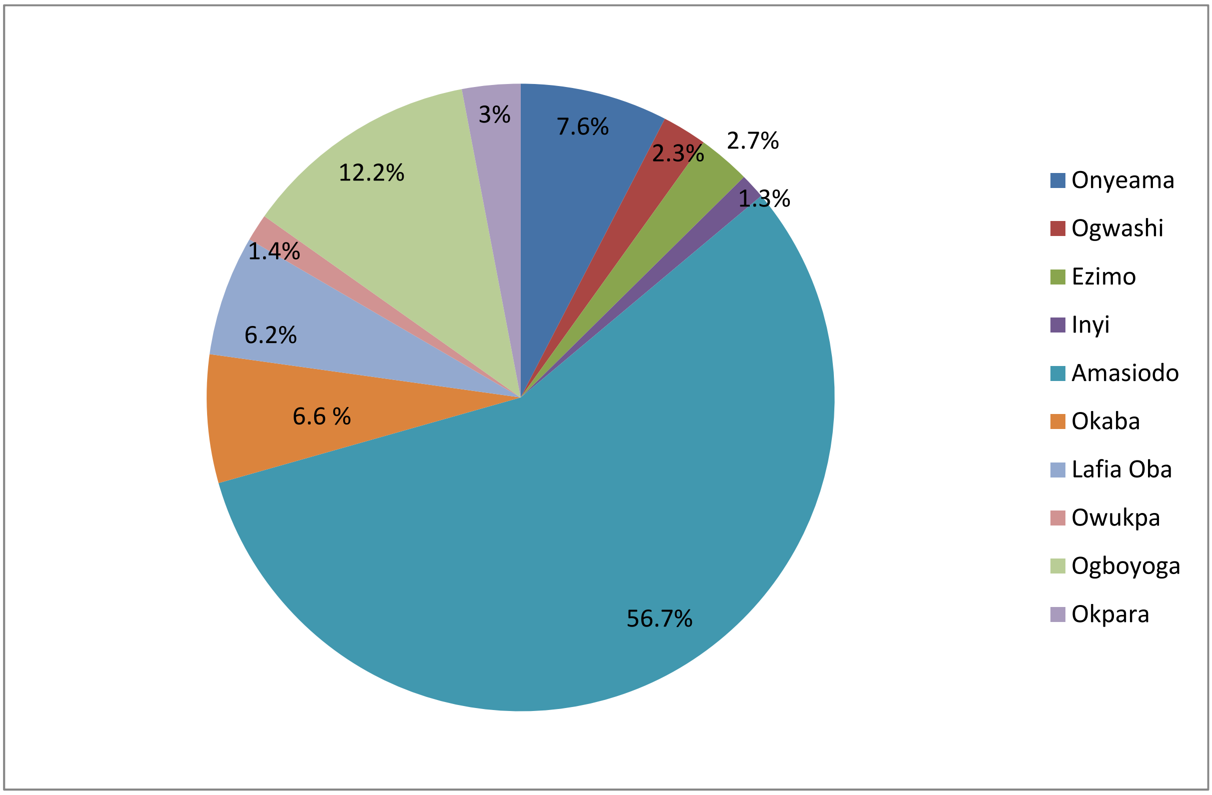

Figure 7 Contribution of each of the coal mines to the potential total energy recovery in applying CBM technology

The emission factor for CBM would be lower than those of PF, USC, FBC and IGCC. According to the Intergovernmental panel of Climate Change (IPCC), from the lifecycle assessment of greenhouse gas emissions from electricity, the emission factor for natural gas is 469g CO_2/kWh. This is lesser than the lowest emission estimated for USC 688g CO_2 / kWh, and 770 g CO_2/ kWh for IGCC, 808 g CO_2/kwh for FBC and 1200 g CO_2/kwh for PF.

There is further opportunity for CO_2 emission reduction in CBM technology, as CO_2 can be sequestered in the coal seam [35-37]. CO_2 is normally used in the recovery of methane from coal seam prior to mining. In the methane recovery process from coal seams, CO_2 is used as an enhancer for methane desorption . Firstly, there is the adsorption of CO_2 to the coal bed and then the methane desorption from the coal bed [38]. The potential CO_2 entrapment in the ten coal mines studied is presented in Figure 8. The total CO_2 sequestration potential for the ten mines is ~55 Mt and Amasiodo coal mine displaying the highest sequestration capacity of 31 Mt and Inyi coal has the lowest capacity with 5Mt.

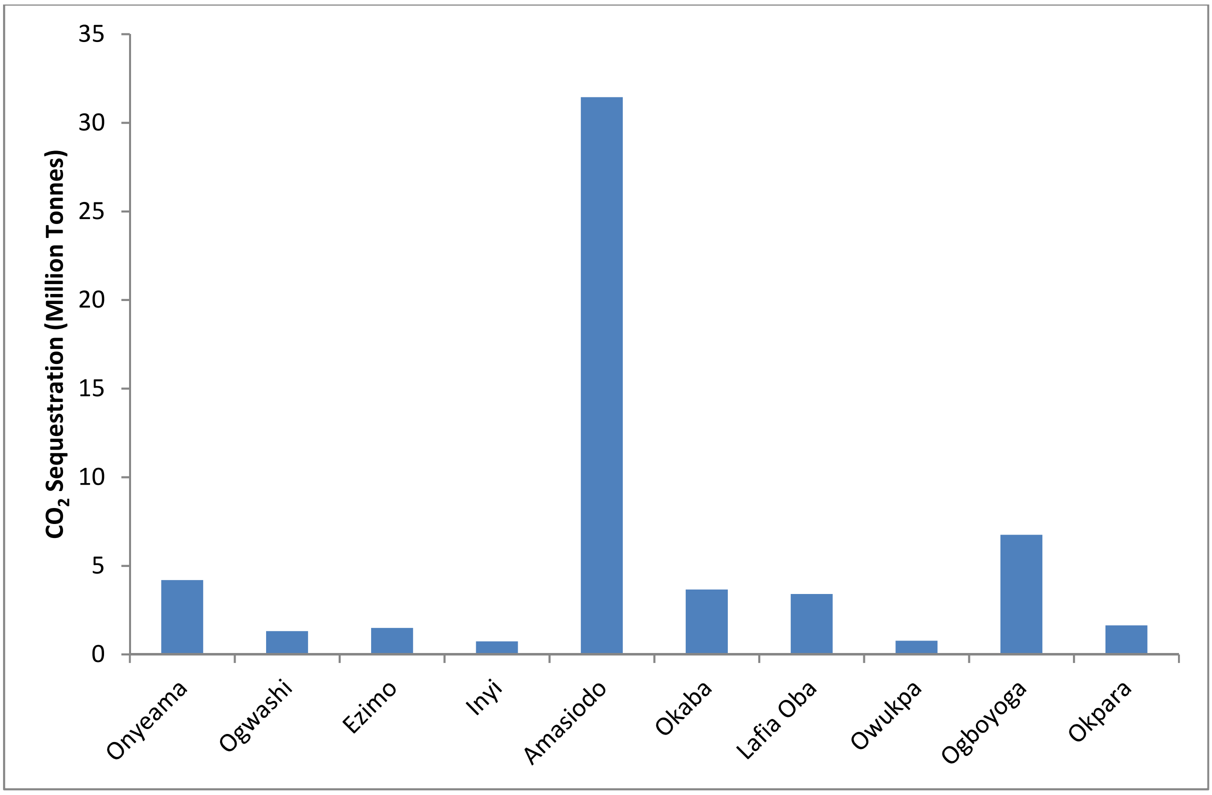

Figure 8: CO_2 sequestration potential for the different coal mines

4. Implications of the results

According to the Nigerian government power growth plan, coal is projected to contribute ~6% of the 40 GW (2.4GW) target in 2020 [10]. Based on the results obtained and using a power plant capacity factor of 85% and a plant life of 30 years, the potential energy recovery from USC, IGCC, FBC and PF, would be greater than the target generation of 2.4 GW from coal by the year 2020. USC will produce 38GW, IGCC 34GW, FBC, 33GW and PF 26 GW. For the CBM technology a generating capacity of 2.4 GW would only be achieved for 8 years.

The average emission factor for CBM (469g CO_2 / kWh) is lower than for all other technologies . The average estimated emission for USC is 688g CO_2 / kWh, for IGCC, 770 g CO_2/ kWh for FBC 808 g CO_2/kwh and for PF 1200 g g CO_2/kwh. This has an implication in terms of project financing. The eligibility of a coal power plant for capital expenditure funding is related to the emission factor. According to the OECD, for a coal fired power plant with an installed capacity greater than 500MW[38], to be eligible for funding, the emission factor should be < 750g CO_2/kWh and the maximum time span for repayment is 12 years. Only two of the ten selected coals meet the emission criteria of < 750g CO_2/kWh and this only with USC coal plants. They are Onyeama (688g CO_2 /kWh) and Okaba (711 g CO_2/kWh). The other eight coals emission factors in a USC plant are higher than 750g CO_2/kWh. Sub critical PF coal plants are not eligible for funding, hence USC technology needed to be considered for coal power plants in Nigeria.

5. Conclusions

An analysis of the effect of clean coal technology on energy recovery and emission reduction was investigated for selected coal mines in Nigeria, namely these are Onyeama, Ogwashi, Ezimo, Inyi, Amasiodo, Okaba, Lafia-Obi, Owukpa Owukpa, Ogboyoga and Okpara. The estimated total reserves of the ten mines amount to 2.1 Gt which is ~84 % of Nigeria's total reserves of the 2.5Gt. The key clean coal technologies studied are Ultra-supercritical Pulverised Fuel Combustion (USC), Supercitical Fluidised Bed Combustion (FBC), Integrated Gasification Combined Cycle (IGGC) and Coal bed Methane (CBM) and the results were compared with that of conventional subcritical pulverised fuel (PF). The total potential energy recoveries are PF 5800 TWh, FBC 7250 TWh, IGCC 7618 TWh, USC 8519 TWh. This indicates an increase of ~31% in the total energy recovery if USC technology is used instead of the conventional PF. About 39% of the total electricity generation of 8178 TWh from USC would come from Amasiodo coal mine making it the highest source of the energy generation and Inyi coal had the lowest source of energy generation (1.5%). The lowest emission factor was for Onyeama coal and was reduced from1.0 kg CO_2/kWh in PF to 0.68 kg CO_2/kWh in USC. Oghwashi coal had the lowest emission factor; there would be a need for upgrading/beneficiation of Oghwashi coal for optimal energy recovery.

The total energy generation potential from CBM is 142 TWh and is lower than the total energy generation potential ofconventional PF technology of 5565 TWh. Amaisodo coal also accounted for the highest share of total potential electricity generation in CBM although it now accounts for 56% as against 39% in PF, FBC, IGCC and USC. Inyi coal had the lowest contribution to the total potential electricity generation in PF, USC, FBC and IGCC and CBM. It was 1.4% in PF, USC, FBC, IGCC and 1.3% in

Amasiodo coal had the higest contribution to the total potential energy generation in PF, USC, FBC and IGCC and CBM. It was 39 % in PF, USC, FBC, IGCC and 58% CBM.

Another interesting finding is that Onyeama coal would have a higher contribution to the total energy generation than Okaba in CBM and this was not the case in PF, USC, FBC and IGCC. This indicates that the fraction of contribution of each coal to the total potential energy recovery would be different. It could either be higher in *ex-situ* technologies (PF, USC, FBC and IGCC) or lower in the *in-situ* technologies (CBM) and the same in both.

The emission factor for CBM is lower than those of PF, USC, FBC and IGCC. CBM to power generation is 469g CO_2/kWh, verses USC - 697g CO_2 kWh, IGCC -779 g CO_2/kWh, FBC- 819 g CO_2/kwh and PF 1023 g CO_2/Kwh . There is also a further opportunity for CO_2 emission reduction in CBM technology. A total of 54 Mt of CO_2 can be sequestrated in the coal mines during the recovery of methane from the coal seams.

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