COMPARISON BETWEEN TECHNOLOGIES FOR THE BEST CHOICE OF A LARGE POWER ELECTRIC GENERATING PLANT BASED ON THERMOELECTRIC WITH COAL OR URANIUM

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Abstract. *Between the alternative sources available for the production of electricity, still lacks reliability for the production in large-scale facilities for base units. For the production of electricity from 500 MW to 1000 MW or more, the coal-fired thermal power plants and nuclear power plants with uranium as fuel have proved competitive and with a high level of reliability and maturation, besides presenting the fuel supply security. This paper presents an analysis of technical feasibility for the choice of the best technology for generating electricity on a large scale, with reliability, based on coal-fired thermal power plants or nuclear power plant using uranium. This paper takes in account the availability of fuel sources, investments costs, thermal power generation systems (boilers and reactors), pollutants emission and mitigation technologies, global efficiency, fuel consumption, CO_2 emissions informations of the main electricity generation technologies, CO_2 sequestration possibilities, costs of electricity generated, average construction time and average lifespan of the installation. Thus the analysis allows the most rational choice of technology for the production of electricity with less environmental impacts, increased security and with the best global efficiency for the production of electricity on a large scale and lower CO_2 emissions.*

Keywords*: Energy, Coal, Uranium, Power Plants.*

1. INTRODUCTION

Between the alternative sources available for the production of electricity, still lacks reliability for the production in large-scale facilities for base units. For the production of electricity from 500 MW to 1000 MW or more, the coal-fired thermal power plants and nuclear power plants with uranium as fuel have proved competitive and with a high level of reliability and maturation, besides presenting fuel supply security.

The coal reserves are large and widely distributed across the continents with efficient commercial technologies for its burning, control and mitigation of generated pollutants, before the flue gases are released into the atmosphere. The overall efficiency of supercritical thermal power plants is already between 43% and 45%, presenting lower coal consumption and low CO_2 emissions, which is one of those responsible for the increased concentration of atmospheric CO_2 and the consequent increase in atmospheric temperature and ocean acidification.

The reduction of CO_2 emissions has become a priority and a challenge for many governments around the world. There are three basic CO_2 sequestration systems in combustion processes, which are: post-combustion capture, pre-combustion capture and oxy-fuel burning. There are already currently available technologies for CO_2 sequestration and storage isolated from combustion processes. In the case of thermonuclear power plants, the nuclear energy is obtained from the fission of the nucleus of an atom of enriched uranium, releasing a high amount of energy. In this case, the emissions of greenhouse gases are approximately zero.

The main problems of thermonuclear plants are related to security, proliferation and proper and safe disposal of the radioactive wastes. The new generations of reactors have several passive systems that ensure greater security. What, then, is the most appropriate or rational technology to be used for a large-scale thermoelectric power plant nowadays? This paper aims to answer this question basing mainly on advanced technologies for power generation and on the mitigation of air pollutants and greenhouse gases emissions into the atmosphere.

2. THE COAL

The coal is an important primary energy source. It is distributed around the world and the reserves are huge, larger than natural gas and oil reserves. Moreover, the coal reserves are not concentrated in a few regions and in these places they have the potential to predicted consumption time of 250 years. This fact eliminates the risks of political instability in particular regions, as has been happening with oil. Besides, the coal is safer for transportation and storage.

Coal prices were significantly higher between 2006 and 2008, but still are lower and more stable than natural gas and oil prices. Thus, coal will remain an indispensable primary energy source in the coming decades in developed countries for electricity production (Stamatelopoulas, 2007).

Coal will continue, in the short to medium term, being a strategic source of energy for underdeveloped and developing countries. It's still the main fuel for electricity generation in the United States of America, Germany, China, India, South Africa, Australia and many countries in Central Europe. In recent years, the positive perception and the growing interest of the industrialized countries, coupled with the efforts in research and development of new clean technologies have intensified the use of coal.

According to the BP Statistical Review of World Energy 2011, by the end of 2010 the proved coal reserves (anthracite, sub-bituminous, bituminous and lignite) totaled 860,938 Mt (BP, 2011).

3. THE URANIUM

Uranium is a relatively abundant metal in the world. It represents about 13,233,763 tons and it's not proportionately distributed around the world. It's extracted from the ore, purified and concentrated in the form of a yellow salt, known as "yellowcake", a raw material for the manufacture of fuel tablets, which in turn will be used for the formation of the fuel elements responsible for the production of the energy generated in a nuclear reactor. The top four countries with the greatest riches of uranium are Australia, United States of America, Canada and Kazakhstan, accounting approximately for 53% of the world's uranium.

The U-235 is the only fissionable isotope of slow neutrons found in nature, although in a small proportion of 0.7% compared with the 99.3% of U-238 in a sample of natural uranium. Thus, for most operating reactors the uranium may be enriched to increase its proportion between 3% and 5%. Brazil has a uranium reserve of approximately 300.3 thousand tons, holding the sixth largest uranium reserve in the world. The deposits are in the states of Ceará, Bahia, Minas Gerais, Pará and Paraná. Brazil also has the technology to enrich uranium.

4. CLEAN COAL TECHNOLOGIES

The clean coal technologies have an important role in the mitigation of environmental impacts due to the intense use of coal expected for the current and coming decades. These technologies are aimed at reducing emissions of SO_2, NO_x, particulate materials, Hg, traces of As and Se, and CO_2.

4.1 Environmental control technologies for conventional plants

The application of the *Flue Gas Desulfurization* System (FGD) has significant impacts on the removal of SO_2 and traces of Hg, As and Se. The arsenic, selenium and mercury emissions in large-scale plants can be effectively reduced by the presence of an electrostatic precipitator (ESP) and FGD or a fabric filter (FF) and FGD. In post-combustion technology the SO_2 control can be accomplished employing the wet, the semi-dry and the dry systems. Of all the coal-fired thermal power plants equipped with FGD systems, over 92.3% adopted the wet gas scrubbers and about 90% used the FGD system with moist limestone (Tian et al., 2011).

The wet FGD process with lime mud removes over 90% of SO_2 and with capital costs being reduced in the last decades. Table 1 provides the potential limits of the control technologies for the reduction of SO_x. The selection criteria for a FGD system depends on the sulfur content, unit size, capacity factor and service life, redundancy, multi-pollutant reduction considerations, reagent cost, quality and availability and sale and disposal of the by-product generated.

For the NO_x reduction, it is employed commercial technologies such as low NO_x burners (LNB), *overfire air* (OFA), reburn, selective non-catalytic reduction (SNCR) techniques, selective catalytic reduction (SCR) and combinations of these technologies. Table 2 provides the potential limits of the control technologies to reduce NO_x. The SNCR system operates at temperatures between 870ºC and 1200°C, while the SCR system operates between 340°C and 380°C.

In the case of particulate material, the technologies employed are mainly possible through post-combustion methods by filters (electrofilters, fabric filter and ceramic filters), wet scrubbers, cyclones and wet or dry electrostatic precipitators (ESP). Table 3 shows the reduction potential of these technologies. Note that the fabric filters presents superior performance compared to ESP technology in the removal of mercury from the flue gas, for most of the mineral coal burnt.

The combination of wet FGD and FF further improves the removal efficiency of mercury compounds, and the removal of traces of As and Se. The physical coal cleaning can remove up to about 60% of existing mercury, one of the most volatile compounds in coal (Wang et al., 2008).

Table 1 – Potential reduction of SO_x control technologies.

Control Technique	SO_x reduction potential (%)
Pré-combustion removal, physical cleaning	30 – 50% removal, inorganic sulfur
Clemical and biological cleaning	90% removal, organic sulfur
Combustion configuration: fluid bed	
Post-combustion removal: wet flue gas desulfurization (FGD)	80 – 98%
In situ sulfur capture: dry sorbent injection (DSI)	50%

Source: Franco and Diaz (2009).

Table 2 - Potential reduction of NO_x control technologies.

Control Technique	NO_x reduction potential (%)
Overfire air (OFA)	20 - 30
Low NO_x burners (LNB)	35 - 55
LNB + OFA	40 - 60
Reburn	50 - 60
Selective non-catalytic reduction (SNCR)	30 – 60
Selective catalytic reduction (SCR)	75 - 85
LNB with SCR	50 - 80
LNB with OFA and SCR	85 - 95

Source: Franco and Diaz (2009).

Table 3 – Potential reduction of MP control technologies.

Control Technique	Reduction potential (%)
Eletrostatic precipitator (ESP)	99% (para 0.1 < d < 10 mm)
Filters	Até 99.9%
Wet scrubber	95 – 99%
Cyclone	90 – 95% (d > 10 mm)

Source: Franco and Diaz (2009).

The progress already achieved enabled the pulverized coal technology in flexibility and operational efficiency in power plants. Modern power plants burning coal achieve greater efficiencies, and these depend on operational parameters such as the coal type, steam temperature and pressure, condenser cooling water temperature, among others.

The efficiency of conventional coal-fired power plants continues to improve each new project designed, so that the new power plants CO_2 emissions are of the order of 15% to 25% lower than than the vast majority of older plants. The supercritical and ultra-supercritical technologies aim to further improve the efficiency of electricity production by burning pulverized coal to values above 50% (CIAB, 2003).

The technical characteristics of supercritical plants such as better efficiency, lower fuel consumption and lower specific emissions make these systems very interesting for CO_2 capture. With more than 400 plants in operation around the world, this cycle has won confidence and operational safety. Ultra-supercritical plants are in operation in countries such as Denmark, Germany, Japan, Italy, China, Canada and the USA (Rezvani et al., 2007; IEA, 2011). The ultra-supercritical power plant Lünen, of 800 MW, in Germany, with steam parameters of 28 MPa/600 C/610ºC, presents a net efficiency above 45% and specific CO_2 emissions well below 800 g/kWh (Cziesla et al., 2009).

A number of ultra-supercritical units, operating at pressures of 32 MPa and temperatures of 600/610ºC, have been built in Europe and Japan. In China, the first ultra-supercritical power plant became operational in November 2006. Materials currently under development and researched are aiming for steam cycle conditions operating at pressures of 36.5 MPa and temperatures from 700 to 720ºC. These conditions would increase the generation efficiency beyond 50%. The coal consumption in these units is up to 21% lower than a subcritical generating unit of 500 MWe both (MIT, 2007; Franco and Diaz, 2009).

The *Oxy-fuel* system, today in marketing, burns a fossil fuel with approximately pure oxygen (above 95%) with flue gas recirculation, in the pulverized coal case, or solids recycling, in the circulating fluidized bed (CFB) case. The atmospheric nitrogen is not incorporated into the products of combustion and this way the flue gas stream produced has a high concentration of CO_2, with can be dried and compressed for storage (geological or oceanic) or other industrial application of interest (Stamotelopoulos, 2007; Buhre et al., 2005; IEA, 2011).

Currently, the direct co-firing system adopted in modern coal-fired power plants has shown efficiencies as high as 45%, with additional investment considered moderate, ranging from US$5/kW to US$50/kW, with an electricity cost considered very competitive depending of the biomass price. In the case of combustion with up to 5% to 10% biomass (in terms of energy), only minor modifications to the handling equipments are needed. The direct co-firing system is being applied in a power plant in St. Andrä, Austria, with wood chips (IEA-Energy Technology Essentials, 2007; Institute for Energy, 2006).

4.2 CO_2 capture and storage

Several CO_2 capture plants were built in the United States in the late 1970s and early 1980s. Some of these plants are still in operation, but all of them are of a smaller size than a typical power plant. The first commercial installation of CO_2 sequestration came into operation in Norway in September 1996. The two main ways to reduce CO_2 emissions from the flue gas of coal-fired power plants are capturing and storing CO_2, which can produce near zero emissions and increase plant efficiency. Each one per cent increase in efficiency represents three per cent reduction in CO_2 emissions and a reduction in the electricity cost (IEA, 2011).

Previous studies have shown that the CO_2 chemical absorption systems based on amine MEA (*monoethanolamine*) are more used in power plants based on combustion for the following reasons: these systems are effective to dilute the CO_2 current, such as gases from coal combustion, which typically contains about 10% to 12 % of CO_2 on its volume. It's a proved technology, it's commercially available and it's being used nowadays; the researches continues to improve the process and rise its potential on mitigating the CO_2. Typically, about 75% to 90% of CO_2 is captured using this technology, producing a flow of CO_2 with purity above 99%.

Industries like *Mitsubishi Ltd* (MHI) and *Kansai Electric Company* (KEPCO) developed nine commercial plants for recovering the CO_2, with capacity up to 450 ton per day (tpd) in chemical and fertilizer industries (Endo et al., 2011).

The development of CO_2 recovery technology has been on going since 1990 in Japan, and it has used an extensive amount of pilots' plants and demonstration tests. Tests have proved the efficiency of the solvent called KS-1 which requires about 20% less energy to capture the CO_2 and shows lower corrosion compared to MEA (Iijima et al., 2005; Oliver, 2008).

Another known process known as PostCap, developed by Siemens, had efficiency above 90% with near zero emission of the solvent and the energy consumption is significantly smaller than other conventional methods. The tests were performed in the pilot power plant Staudinger, with over 3,000 hours of operation (Siemens, 2010).

It's necessary to highlight that the presence of acid impurities like SO_2 and NO_2 in flue gases from power plants affect the CO_2 removal system performance and costs. The addition of a FGD process or an upgraded version of FGD is essential to reduce the costs of removing carbon (Rubin and Rao, 2011).

Hitachi also developed the solvent so-called H3, which showed a higher efficiency in the CO_2 capture than the MEA. Its regeneration specific heat is of 2800 kJ/kg CO_2, while MEA consumed 3600 kJ/kg CO_2 in the same power plant (Stover et al., 2011).

The need for mitigation of CO_2 will require power plants that enable the capture of CO_2 in a short term. This will involve a greater consumption of biomass and fuel of low quality, improvement in the efficiency of the plants, mainly by using advanced supercritical and ultra-supercritical steam cycles (Suraniti et al., 2009).

5. ADVANCED POWER GENERATION TECHNOLOGIES

Advanced Power generation technologies represent an alternative to conventional technologies in order to increase plant efficiency and reduce the CO_2 emissions. They also aim to reduce the requirement of disposal to solid waste and raise the economic advantages. The two most important technologies available for burning coal are:

- Combustion in a Fluidized Bed (CFB)
- Combined Cycle with integrated Gasifier (CCIG).

The FBC technologies are diversified. These include atmospheric fluidized-bed combustion, circulating fluidized-bed combustion or pressurized fluidized-bed combustion and circulating pressurized fluidized-bed combustion. The controlled combustion allows flexibility in the use of low quality and low volatility fuels. The efficiency is in between 42% to 45%.

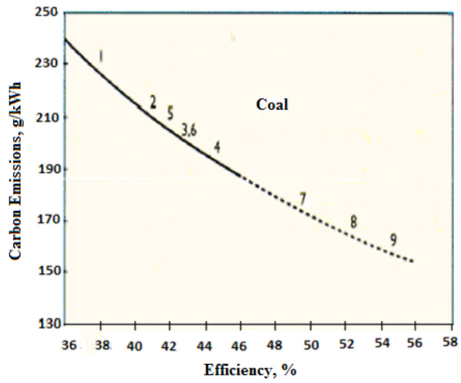
The boiler operation requires skilled operators and with good experience. It is used the integrated desulfurization system when the contest of sulfur is high, utilizing the CaO of the boiler, without the need for other absorbent (Franco and Diaz, 2009; Stamatelopoulos, 2007). Alston is producing supercritical fluidized bed boilers of 600 MWe (Suraniti, 2009).

The second generation of pressurized fluidized-bed boilers with *Topping* cycle should have efficiency increased to 47% and with N_2O emissions near zero. The IGCC technology is a power generating process which includes a gasification system with a combined cycle power plant (Rankine/Brayton). The IGCC technology converts coal in a synthetic gas consisting primarily of H2 and CO, which may then be refined and used clean. The gas produced from the coal gasification is burned in gas turbines of thermoelectric power plants. The IGCC power plant has the potential to increase the net efficiency of 50% or more, with the use of gas turbines and advanced boilers.

Due to the high efficiency of IGCC plants, the CO_2 emissions per electric energy unit produced are reduced (Ortiz et al., 2009). This technology presents lower costs and easier removal of pollutants and CO_2 capture than conventional power plants with CO_2 capture from post-combustion flue gas (Oh, 2010). There are plants in operation in the United States, Netherlands, Spain, Germany, Italy, Singapore, Japan and under construction in China. In Asia, the IGCC technology began in 2000 (Hoffmann and Szklo, 2011).

According to Intergovernmental Panel on Climate Change (IPCC) studies of 2005, the emission factors for pulverized coal-fired plants without CO_2 capture are between 736 and 811 kg CO_2/MWh and for IGCC plants between 682 and 846 kg CO_2/MWh. With CO_2 capture, the values are reduced to between 92 and 145 kg CO_2/MWh for pulverized coal-fired plants, and between 65 and 152 kg CO_2/MWh for IGCC plants (Rubin et al., 2007). The pulverized coal-fired and fluidized bed plants take on average 3 to 4 years to be built, while the IGCC plant takes about 4 to 5 years. Besides their ability to add CCS systems, the IGCC technology has other advantages such as low emissions of sulfur and mercury compounds and greater flexibility on inputs and outputs of the process (Beer, 2009; IPCC, 2005).

In the UK the historical improvement in the coal-fired plants efficiency is shown in Fig. 1. The average efficiency of a power plant burning coal in the UK is around 35%. If this plant was designed by the best available technology (BAT) of today, it would have an efficiency of aboput 45%, leading to reductions around 25% in CO_2/MW of electricity produced (Oliver, 2008). Figure 1 shows the CO_2 emissions and efficiencies of various conventional and advanced technologies, analyzed in the work of Oliver (2008).



Plant Type	Efficiency with tower (%)
1 Subcritical PF with FGD	38 (typical)
2 Subcritical PF with FGD	41 (best available)
3 Supercritical PF with FGD	43 (typical)
4 Supercritical PF with FGD	45 (best available)
5 PFBC	42 (demonstration)
6 IGCC	43 (demonstration)
7 PFBC (2010)	50
8 IGCC (2010)	53
9 Supercritical PF (2010)	55

Figure 1: Efficiency improvements and impact on CO_2 emissions. Source: Oliver (2008).

6. NUCLEAR POWER PLANT

The nuclear power is an important source of electricity, supplying approximately 19% of the electricity demand on Earth. According to the World Nuclear Agency – WNA, the number of reactors in operation worldwide reached 438 in April 2010, distributed in 30 countries and regions. The installed capacity reached 374,127 MWe, supplying 2,560 TWh of electricity generation in 2009 and an increase in capacity predicted to 575,619 MWe in 2010 (Yan Q. et al., 2010). The majority of reactors in operation are technically classified as thermal neutron reactors. The nuclear fission reactor produces heat through a controlled chain reaction in a critical mass of fissile material. They are classified into:

- Pressurized Water Reactors (PWR);
- Boiling Water Reactors (BWR);
- Pressurized Heavy Water Reactor (PHWR);
- High-Power Channel Reactor (RBMK);
- Gas-Cooled Reactor (GCR) e Advanced Gas-Cooled Reactor (AGCR);
- Liquid Metal Fast Breeder Reactor (LMFBR);
- Aqueous Homogeneous Reactor.

Advanced reactor designs are in research and in development. Among them there are the High Temperature Gas-Cooled Reactor (HTGCR), the Thorium-based Reactors and the Advanced Heavy Water Reactor (AHWR). Others who are in research are called Generation IV reactors. Among these, it can be cited the Gas Cooled Fast Reactor (GFR), the Molten Salt Reactor (MSR), the Supercritical Water Reactor (SCWR) and the Very High Temperature Reactor (VHTR).

The renewed interest in the increase of nuclear power came from the improved in the performance of existing reactors, federal incentives in energy policy, the possibility of controlling the CO_2 which increases the fossil power plants cost, the possibility of diversifying energy sources and the natural gas prices volatility.

After the Fukushima accident in Japan, security issues related to a possible blackout in thermonuclear plants, resulted in the decision that must be installed a bank of batteries that will promote power for 4 to 8 hours of operation thereof. However, questions about the reactors vulnerability to natural disasters and the hydrogen release due to overheating of the fuel elements need to be researched and resolved.

Moreover, questions about nuclear waste and risks of burned uranium proliferation for manufacture of nuclear weapons also require solution, as cast some doubt on the viability of building new thermonuclear and operation of existing ones.

The thermal power plants shows low efficiencies (30% to 33% on average) compared to coal-fired power plants. The implantation of hybrid combined cycle (gas turbine, superheater and nuclear power plant) increases the total efficiency to values in a range from 46% to 52% (Darwish et al., 2010). Nuclear plants are commercially available in the type LW-PWR, LW-BWR, HW-PWR, known as CANDU and HTGR. These plants have high capital costs, but present low variation in operating costs, including low fuel costs. It can have load factor above 80%, construction time of 40 to 60 months and lifetime of 40 to 60 years. Best use of natural resources and a decline in the amount of waste generated will be obtained with the generation IV nuclear reactors, which are in development (Marques, 2010).

7. ELECTRIC POWER PLANTS COSTS

The prices rice mainly due to the growth of construction costs, rising prices of metals and plant components, as well as the imbalance between demand and supply in the field of construction of power plants. According to Risto Tarjanne and Aija Kivistö (2008), the electricity production costs for nuclear power plants were 35.0 €/MWh and based on coal without CO_2 capture the costs were 45.7 €/MWh.

According to report of DOE/NETL of 2007, the total cost of the plant (capital cost), without CO_2 capture (CC), was \$1562/kW for pulverized coal-fired plants and \$1841/kW for IGCC plants, on average. With CO_2 capture, was at \$2883/kW for PC plants and \$2496/kW for IGCC plants, on average. In the IGCC plant, the CO_2 capture is less expensive than other coal-fired power plants, as the CO_2 removal is performed before combustion. That is, the removal is performed from the stream of synthesis gas, instead of the exhaust stream, thus having a much lower volume, higher CO_2 concentrations and higher gas flow pressure (Zhao, et al. 2,008; IPCC, 2005).

The National Energy Technology Laboratory (NETL) report of 2010 presented the total overnight cost for power plants without CO_2 capture of \$2,010/kW for PC and an average of \$2,505/kW for IGCC plants. With CO_2 capture, the capital costs were \$3,590/kW for pulverized coal and an average of \$3,568/kW for IGCC plant, with the coal cost at \$1.64/MMBtu.The electricity cost without CO_2 capture is an average of \$59/MWh for pulverized coal and an average of \$77/MWh for IGCC plants. With systems integrating CO_2 capture and storage, the electricity costs rice to \$108/MWh for pulverized coal and rice to \$112/MWh in IGCC plants (NETL, 2010).

In 2007 the capital cost of thermonuclear power plants type LW-PWR (AP 600 e AP 1000) was \$2.865/kW and in 2008 the investment cost of thermonuclear power plants type BWR and PWR with estimated power of 1500 MW was around 2.750 €/kW and for coal-fired power plants with a capacity of 500 MW and efficiency of 42% in 1.300 €/kW.

According studies by Hoffmann and Szklo (2011), the levelized cost of electricity (LCOE) for PC plants without CC were in the range of US\$57.80/MWh to US\$81.60/MWh and, for IGCC plants with CC, in the range of US\$81.00/MWh to US\$151.00/MWh, reflecting much on the U.S. market (Hoffmann and Szklo, 2011). Figure 2 shows the electricity costs for the various technologies and capacity or load factors, making it clear that the increase in the capacity factor leads to the decrease of the electricity cost from the plant.

Table 4 provides the technical and economic parameters of some technologies for generating electricity. Prices increase due to the growth of the construction costs, rising prices of the metals and plant components, as well as the imbalance between demand and supply in the field of construction of power plants.

Table 4 - Technical and economical parameters of the any technologies.

Technology	CCS	Fuel Type	Capacity (MWe)	Captal Cost (US\$/kW)	Efficiency (%)	Load Factor (%)	Fuel net calorific value (GJ/t)	Fixed O&M (US\$/kW Month)	Variable O&M (US\$/MWh)
Rankine cycle	No	Coal	250	1380	36.2	50-90	26.8	4.51	2.26
Rankine cycle	No	HFO	250	1320	37.3	50-90	41.3	2.97	0.49
Combined cycle	No	Gasoil	250	1000	50.8	50-90	42.5	2.71	4.64
Combined cycle	No	Natural gas	250	1000	53.5	50-90	45.0	2.48	2.50
IGCC	No	Coal	250	1450	40.0	50-90	26.8	3.60	1.75
IGCC	No	Coal	250	1450	45.0	50-90	26.8	3.60	1.75
IGCC	No	Coal	250	1450	50.0	50-90	26.8	3.60	1.75
IGCC	No	Coal	250	1450	55.0	50-90	26.8	3.60	1.75
IGCC	Yes	Coal	250	2000	40.0	50-90	26.8	4.0	1.78
IGCC/CCS	Yes	Coal	250	2000	45.0	50-90	26.8	4.0	1.78
IGCC/CCS	Yes	Coal	250	2000	50.0	50-90	26.8	4.0	1.78
IGCC/CCS	Yes	Coal	250	2000	55.0	50-90	26.8	4.0	1.78

Source: Christou et al. (2008).

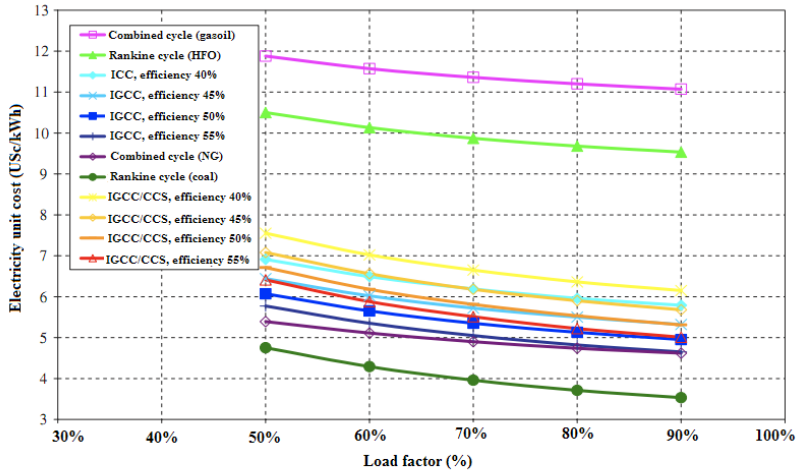


Figure 2: Electricity unit cost for various capacity factors. Source: Christou et al. (2008).

According to Smouse (2011), advanced PC plants present capital costs of $2,800/kW and emissions of about 1800 lbs CO_2/MWh, on average, and IGCC plants present capital costs of $3,100/kW and emissions from 1700 lbs CO_2/MWh. For advanced nuclear plants, the values were approximately $5,300/kW without CO_2 emissions (Smouse, 2011).

Tick Hui Oh (2010) reports in his work that the estimated costs for CO_2 capture and storage range from US$30 to US$70 per ton depending on the technology and the CO_2 concentrations in the stream. The CO_2 capture, separation and compression alone will increase the cost of electricity produced from US$43/MWh to around US$61 to 78/MWh for new power plants, and from US$17/MWh for values around US$58 to 67/MWh for coal-fired power plants that already have been amortized (Oh, 2010).

8. CONCLUSIONS

The combustion of pulverized coal in a supercritical or ultra-supercritical boiler is the best choice for new power plants to produce electricity on a large scale in the short and medium term, with a load factor equal to or greater than 80%. The high efficiency and lower prices of coal provide lower electricity costs, lower fuel consumption and lower CO_2 emissions to the atmosphere, and is a safe and reliable technology, with a construction period of two to three years. In addition, provides a high maturity.

For countries that have coal reserves of low quality (lower calorific value, high sulfur percentages, moisture and ashes) the best choice is the supercritical circulating fluidized bed combustion technology, which provide greater emissions control of pollutants into the atmosphere and great flexibility in the use of coal, despite the higher initial cost.

If there is strict government regulation to control carbon emissions, the most lucrative choiceis the IGCC technology with CCS integrated, despite the initial capital cost being generally higher. Additionally, it is possible generate electricity primarily with the gasifier system and the Brayton cycle, before the construction of the Rankine cycle.

For countries that do not have coal reserves, do not have a history of earthquakes and tsunami, a good choice would be the advanced nuclear technology that presents CO_2 emissions approximately equal to zero and passive safety systems. Despite the higher initial capital cost, compared to other available technologies, the electricity generated cost is smaller than the existing technologies. Moreover, the life span can reach 60 years (generations III and III +) and variations in the costs of uranium fuel hardly influence the final values of the cost of electricity produced by the plant.

It is important to remember that the construction time of a nuclear plant is around 5 to 6 years, compared to the 2 to 3 years, on average, to build an advanced coal-fired thermal power plant.

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