**IMIA WGP58 (08)**

# $CO_2$ Free Coal Combustion Technology – Influence on Insurance


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**Abstract:**

This paper discusses technologies for carbon dioxide capture when burning fossil fuels for electrical power generation. It discusses the use of coal in power generation and the need for $CO_2$ capture. It presents an overview of the technologies in development, their anticipated commercialisation date, and reviews relevant insurance concerns. This paper does not discuss the risk associated with carbon sequestration as this is perceived as a topic worthy of a stand alone paper.

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# 1. Scope of coal in power generation

Fossil fuels are the dominant fuel source of power generation in the US and world-wide. Of the fossil fuels, coal is the leading fuel choice. In the US, coal accounts for more than 48% of the electricity generated (Figure 1).[1] On a worldwide basis, coal accounts for almost 41% of the power production (Figure 2). [2,3]

Figure 1:

**Percentage of US Power by Fuel, Jan - Nov 07**

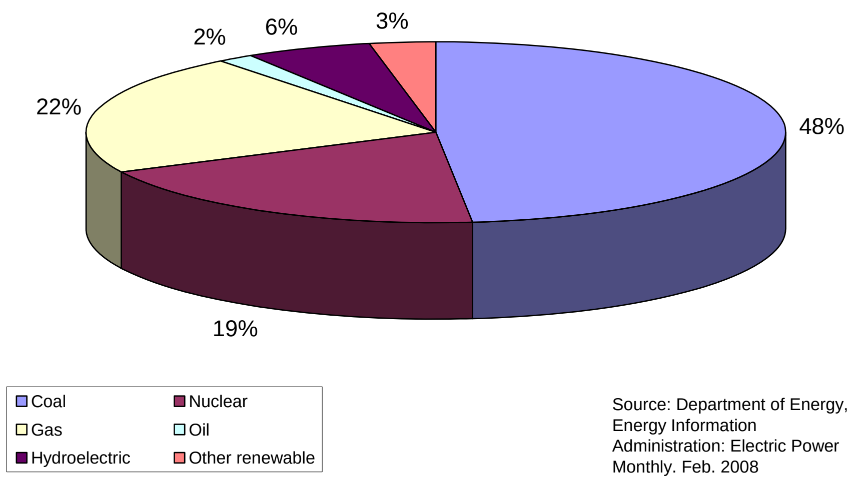
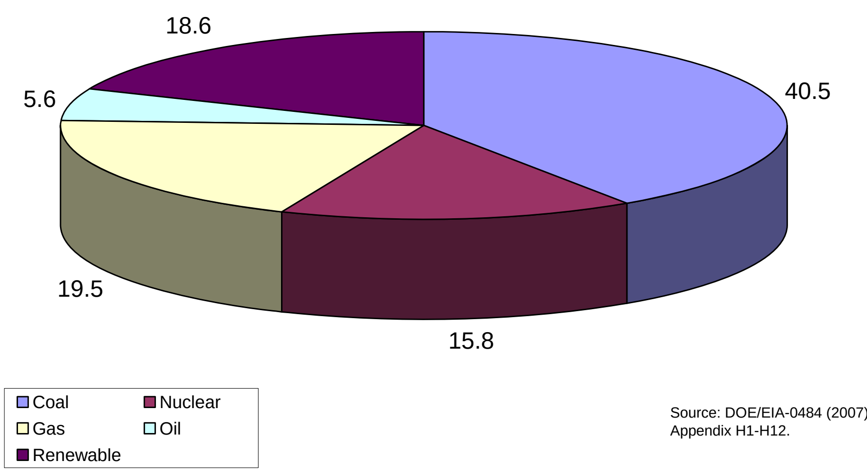



Figure 2:

**Percentage of Fuels used in World Power Production**



## 1.1 Coal Reserves – United States & Worldwide

When looking at the long term viability of coal one must evaluate the coal reserves to determine if the current rate of power generation is sustainable or if it must decline because of limited quantities. Based on the following information, it is apparent that there is an ample supply of coal reserves and there will be no immediate reduction in the current usage. And because of this large reserve, there may be an expansion in the number of facilities which burn coal. Especially in developing countries where coal may be the lowest cost fuel available.

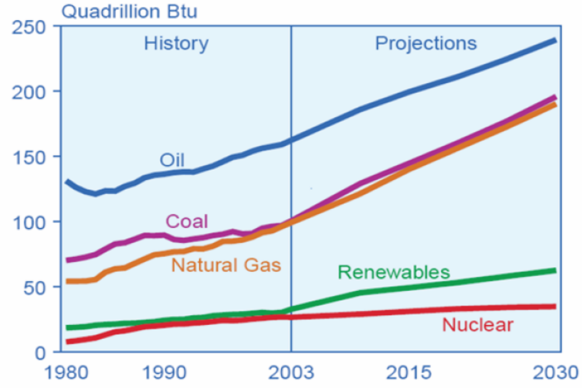
The US coal reserves are estimated at 242 billion metric tons with an annual production of about 1.055 billion metric tons.[4] While the exact amount of coal available is cited differently from different sources, the scale of the reserves remains the same. Based on these numbers there is enough coal for more than 230 years of use at the current rate of consumption. The United States Department of Energy (DOE) predicts coal will remain the dominant fuel source for electrical power generation for many years. The DOE predicts that coal will increase to about 57% of the energy produced in the year 2030.[5] It is important to remember that the US, and other countries, have developed extensive infrastructures around coal. These include the ability to efficiently mine coal from the ground, transport the coal to an end user, and burn it to produce electricity. These investments in infrastructure represent an enormous expenditure of money and companies will be slow to abandon this investment.

On a global basis, the world coal reserves are estimated at 905 billion metric tons with a current production of 5.89 billion (2005 estimates). Using these numbers there would be approximately a 154 year supply of coal with the known reserves.[6] As with the US, the known world reserves will allow for many years of continued use.

As an example of coal's continued dominance, in 2006 China built 90,000 MW of coal fired capacity. This exceeds the entire generation capacity of the United Kingdom by 13,000 MW.[7]

The following table shows the world market energy use by energy type from 1980 through 2003 as well as projections to the year 2030. It not only shows a continued use of coal but it predicts a sizeable increase in its use.

World Marketed Energy Use by Energy Type, 1980-2030




Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2003* (May-July 2005), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2006).

## 1.2 Renewable Energy

Power generation from renewable, or green, energy has become the focus of extensive research, media coverage and implementation. Renewable energy comes in many different forms but the most discussed and utilised are hydro, wind and solar. While renewable energy is often discussed and debated as a viable energy source, it currently accounts for a very small portion of the total power generated on a worldwide basis.

While renewable fuel sources are generally considered free, concerns with fuel reliability exist. For example, wind power is intermittent, the sun is often blocked by clouds, and droughts impair hydropower production. Currently, these technologies only supplement grid power. Extensive debates continue on how much renewable energies can accommodate an area and how much reserve power is needed to maintain a stable electrical grid.

Additionally, most renewable energy technologies are not competitive with traditional methods of generating electricity on an economic basis. As a result, they must rely on government incentives to be economically competitive. This will become a greater issue as we move toward carbon capture and the associated cost. With the addition of carbon capture into coal burning plants, the cost of power generated may become closer to the subsidised renewable energies and make renewable energy installations more prevalent. Many developments addressing these problems are in the works, but coal will be needed as a primary energy source to balance the small and often intermittent electricity generated from renewable sources.

## 1.3 Nuclear Energy

One alternative that should impact coal's dominance as a fuel choice is the proliferation of nuclear energy. While nuclear energy is a sizeable portion of the total generation capacity, there have not been any new nuclear plants built in the United States in over 20 years. Also, nuclear plants are generally operated at full load and cannot accommodate the ever changing demand for electricity (load following). This gap is filled by fuel sources such as coal, oil and natural gas. Additionally, many nuclear power plants are nearing the end of their design life and without re-licensing they must close, thereby increasing the need for large scale new power generation facilities. Coal certainly meets this need.

On a global basis, nuclear power continues to be developed and expanded with much debate over its proliferation, issues associated with radioactive waste and its possible influence on weapon programs. Without question, electricity from nuclear power will continue to be a large portion of the generating profile but it is not expected to diminish the need for coal fired generating stations.

## 1.4 Facility retrofits

With the high cost to replace carbon dioxide ($CO_2$) producing sources of electricity, it can be assumed that it will be more economical to retrofit existing plants rather than to replace them with new sources. As a result, this paper includes both new and retrofit technologies.

## 1.5 Regulatory Uncertainty

With the regulatory uncertainty it is difficult for companies to economically justify spending billions of dollars on a new fossil fuel fired facility when at completion it may not meet the new and changing carbon dioxide emission regulations. This uncertainty may also result in additional incremental facility expansion, and additional capital spending on the existing facility in order to remain in operation. This level of uncertainty may prevent companies from investing in full scale carbon capture technologies. However, there are many companies which are investing in pilot plants to better understand the challenges associated with carbon capture before moving to full scale implementation. In Section 2, the impact of this regulatory uncertainty can be seen with the cancellation of several coal fired facilities.

## 1.6 Summary

When looking at the long term outlook for coal it is difficult to dismiss it as a continuing source of fuel for power generation and it would be impossible to simply eliminate coal as a source of power generation without shutting down the grid. The numbers show the global dependence on coal for the generation of electricity and there is no quick and easy solution for replacement power. Therefore, coal will remain the leading fuel for the generation of electricity and carbon capture technologies will need to be developed and implemented.

## 2. Is there a need for $CO_2$ capture?

Regardless of whether $CO_2$ is a direct cause of global warming, a lagging indicator or is unrelated, there is global concern for the rising atmospheric concentration levels. With this increase in $CO_2$ levels, there are several factors which will influence the need for $CO_2$ capture. The two most prevalent factors are global climate change and governmental regulations. The technical merit regarding the influence of man-made $CO_2$ on global warming is debated by many scientists and only time will tell who is correct. This paper will not discuss the merits of global climate change or the environmental impact of $CO_2$ concentrations. Instead, it will focus on the associated reaction to this perception/reality.

Most, if not all, world governments acknowledge global warming as a concern and they have, to some extent, agreed that $CO_2$ is a contributing factor. As such, they believe that legislation can help to control this pollutant thereby helping to mitigate the effects of global warming. The legislation has and will take many forms, through international agreements like the Kyoto Protocol, to federal "cap & trade" programs, to local governments mandating lower emissions from nearby power plants. It is generally accepted that when the technology proves itself as commercially viable, additional $CO_2$ regulation will be created.

As discussed previously, coal is the predominant fuel source for power generation and should continue to be so for many years. Unfortunately, $CO_2$ is a by-product of electrical power generation with fossil fuels. Therefore, it will be necessary to continue development of methods to eliminate or reduce this component of combustion.

Great strides have been made in the past 20 years in methods to reduce or eliminate pollution associated with burning coal in power generation facilities. $NO_x$ control has developed with the advancement of selective catalytic reduction (SCR) systems and low $NO_x$ burner systems; $SO_x$ reductions continue with flue gas desulphurisation (scrubbers); and particulate matter removal with electrostatic precipitators (ESP) and bag houses. These technologies have developed through theoretical development, bench testing, small scale implementation, full scale installation and commercial development. Power generation companies are comfortable with the technology; legislative efforts are demanding its implementation and installations continue at a rapid pace around the world. Carbon capture has not completed this evolution. These commercially available environmental technologies are an integral portion of some carbon capture technologies. For example, methanol and amine scrubbers are in commercial operation to separate mixtures of $SO_x$ and $CO_2$ within the coal gasification process.

The need to develop the ability to capture $CO_2$ can also be seen in the recent United States cancellations of new coal burning power generation plants and the cancellation of plant retrofits because of uncertainty in the $CO_2$ legislation. In Europe, public sentiment and government regulation has prevented the proposal of new coal burning power generation facilities almost entirely. The following is a list of recent press releases and newspaper headlines regarding proposed new coal fired power generation facilities in the United States.

- Idaho Power Co.; Project cancelled due to permit issues and emissions concerns; 250 MW plant; November 2007. [8]
- Kansas – Sunflower Electric Power Corporation; two 700 MW units; permit denied citing emissions concerns; October 2007.
- AEP & Oklahoma Gas & Electric – Red Rock Generating Station; 950 MW facility; regulators denied permit; September 2007.[9]
- Florida – Seminole Electric Power Cooperative; Seminole 3 Generation Station; 750 MW; Permit denied by Florida Department of Environmental Protection; August 2007[10]
- Florida – FPL – Glades Power Plant; 1960 MW; Public Service Commission ruling denying a clean coal power plant; June 2007.[11]
- Tampa Electric; Polk 6; 623 MW Integrated Gasified Combined Cycle (IGCC) power plant; cancelled due to uncertainty about future carbon regulation.[12]

In order to proceed with the installation of new coal fired electricity generating stations $CO_2$ capture technologies will need to be developed for full scale implementation. And, as new facilities are constructed with the ability to limit $CO_2$ emissions, existing facilities will be required to meet these new emission requirements thereby increasing the need to retrofit existing facilities and further proliferate the technology.

## 3. Leading $CO_2$ capture developments

With the social, political and regulatory pressures, owners and manufacturers are more interested in $CO_2$ capture technologies. Power generation conferences now include carbon capture technology tracks with excellent attendance and an abundance of presentations. Governments are funding research and development. In the US, the FutureGen project focused on coal but was heavily debated because it focused on only one technology. Eventually, the FutureGen project was cancelled but the funds were not removed. Instead, the US government is using the funds to spur development of multiple technologies associated with coal, one of which is carbon capture and sequestration.

Numerous companies have announced pilot projects and committed money to develop technologies for carbon capture. The focus is to develop pilot projects for early technology development before scaling up to commercial size. Below are examples from some, not all, of the announcements made over the past two years.

- German company Vattenfall plans on constructing the first pilot oxyfuel coal fired plant. Combustion will occur in an oxygen rich, nitrogen deficient environment, and re-circulate the exhaust stream before capturing the $CO_2$. The plant is designed for a 30 MW thermal capacity, and represents an initial step in overall testing of the oxyfuel process in a large scale technical application. The activities focus on testing component integration and $CO_2$ separation purity. Operations should commence by mid 2008, with testing to continue for roughly 3 years. If successful, a demonstration power plant of 250-300 MW electric capacity is proposed. This will act as a large-scale profitability and optimisation test for a larger, 1,000MW plant proposed between the years 2015-2020.

- "NRG and Powerspan announce large-scale demonstration of carbon capture and sequestration for coal-fueled power plants" – In November 2007, NRG and Powerspan Corp. announced a memorandum of understanding to demonstrate commercial scale carbon dioxide capture technology. The technology is a post-combustion, regenerative process using an ammonia-based solution to capture $CO_2$ from flue gas of a power plant and release it in a form ready for transportation and permanent geological storage. Powerspan's ECO2 demonstration facility will be designed to capture 90 percent of incoming $CO_2$ and is expected to be operational in 2012. The carbon capture and sequestration (CCS) will be conducted on the W.A. Parish Plant near Sugar Land, Texas, USA on a 125 MW unit. It's expected to capture and sequester about one million tons of $CO_2$ annually. It will rank among the world's largest CCS projects and potentially the first to achieve commercial scale capture and sequestration from an existing coal fueled power plant. [13]

- FutureGen: Although this US government project has been suspended, the funds are being redistributed to further develop clean coal technologies. The DOE requested $241 million dollars to demonstrate technologies for cost effective carbon capture and storage for coal fired power plants. This includes $156 million for the restructured FutureGen approach aimed at commercialising the technology by 2015 and $85 million for a Clean Coal Power Initiative.

- Basin Electric and Powerspan Corp announced a demonstration project for Powerspan's carbon dioxide capture technology at the Antelope Valley Station located near Beulah, North Dakota, USA. It's a 120 MW plant and will capture one million tons of $CO_2$ annually. The facility is expected to be operational in 2012. Powerspan's $CO_2$ capture process, called "ECO2™," is a post-combustion, regenerative process, which uses an ammonia-based solution to capture $CO_2$ from the flue gas of a power plant and release it in a form that is ready for further compression, safe transportation, and geological storage.[14] The Basin project is estimated to cost $200 million USD.[15]

- American Electric Power (AEP), the French engineering company Alstom, and the German utility conglomerate RWE are partnering to prove that carbon dioxide can be removed from a coal fired plant's exhaust. The system being installed on the Mountaineer Plant will be one of the first large-scale validations of carbon-capture technology in the world. A chilled ammonia process developed by Alstom will be used to convert the carbon dioxide into a liquid. The liquid will be pumped 3.2 km (2 miles) underground, where it will be permanently stored in a porous, 30 to 45 meter thick (100-140 ft) rock formation. The leftover exhaust will be sent back up to the stack. The plant will take about 20 MW worth of the 1,300 MW plant exhaust using Alstom as the operator for the first five years. If it succeeds, AEP and Alstom will move to commercial scale-up.[16]

- Doosan Babcock Energy announced in February 2008 that it was starting a new project called "Oxycoal 2" to demonstrate the Oxyfuel technology for carbon capture on coal fired power plants. The $14.5 million project is being supported by the Department for Business Enterprise and Regulatory Reform (BERR) under its Hydrogen Fuel Cells and Carbon Abatement Technologies (HFCCAT) Demonstration Programme and by a group of industrial sponsors and university partners comprising Scottish and Southern Energy (Prime Sponsor), E.ON UK PLC, Drax Power Limited, Scottish Power, EDF Energy, Dong Energy Generation, Air Products Plc (Sponsors), and Imperial College and University of Nottingham (University Partners). Doosan Babcock will modify its Multi Fuel Burner Test Rig at Renfrew to accommodate Oxyfuel firing on pulverised coal with recycled flue gas and demonstrate the operation of a full scale 40 MW burner for use in coal fired boilers, suitable both for new power plants being built around the world and for retrofit applications.[17]

- Dominion Energy donated $500,000 to Virginia Canter for Coal and Energy Research and their carbon capture project.[18]

- AEP with GE Energy and Bechtel Corporation are performing the front-end engineering design process for an IGCC plant in the 600 MW range. The plant will be located in the Ohio, Kentucky and West Virginia area of the US.[19]

- Alstom, the Electric Power Research Institute (EPRI) and WE Energies announced that the first pilot project that uses chilled ammonia to capture carbon dioxide ($CO_2$) from coal fueled power plants is expected to commence operation during 2008. Alstom designed, constructed and will operate the 1.7 megawatt system that captures $CO_2$ from a portion of coal fired boiler flue gas at We Energies' Pleasant Prairie Power Plant, a 1,210-megawatt coal fired generating station. Alstom's process uses chilled ammonia to capture and isolate $CO_2$ in a highly concentrated, high-pressure form. In laboratory testing it has demonstrated the potential to capture more than 90 percent of $CO_2$ at a seemingly lower cost than other carbon capture technologies. Once captured, the $CO_2$ can be used commercially or sequestered in suitable underground geologic sites.[20]

- Peabody & ConocoPhillips announced in July 2007 that they have entered into an agreement to explore development of a commercial scale coal-to-substitute natural gas (SNG) facility using proprietary ConocoPhillips E-GAS™ technology.[21]

- Many IGCC technologies do not include carbon-capturing technologies. As such, they are trying to perfect the gasification process before moving to the next step of capture then the next step of sequestration. China is developing what they call GreenGen, but in its initial phase it won't feature any carbon capturing devices. Australia and Europe are in the same position.[22] While there are extensive discussions on the topic, as of November 2, 2007, only projects on a pilot scale or one to five MW have been constructed.[23]

## 4. Challenges associated with $CO_2$ capture

There are many challenges associated with $CO_2$ capture that need to be overcome by each of the technologies discussed in the following section. Additionally, there are questions as to what will happen to the $CO_2$ after it's captured. Sequestration is an option but it has many complexities associated with site selection, transportation, and long term liability to name a few.

The cost of building a new facility able to capture $CO_2$ may cost more than other methods of generating electricity. Therefore, without some form of government regulation, new facilities will not be built and the technology will not advance.

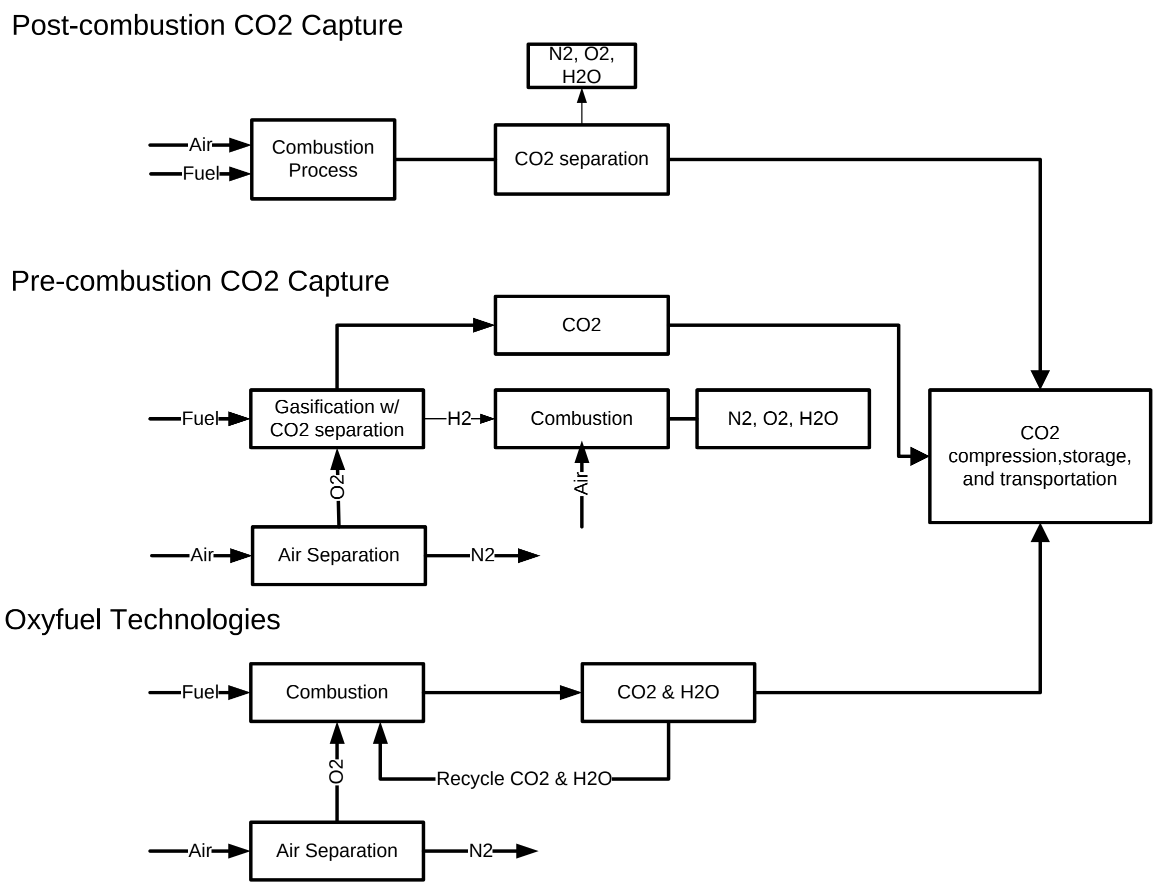
The cost of retrofitting an existing facility for $CO_2$ capture will be a large financial burden for the existing owner operators and there is uncertainty regarding transfer of these costs to the end user. Modification of an existing facility will have a large impact on the physical footprint of the plant and some facilities will not have the real estate required for modification. The additional footprint is roughly estimated to be the same as an existing coal fired facility; i.e., the overall footprint will double, with half being for power generation and half for $CO_2$ separation.

The amount of $CO_2$ that will be allowed in an exhaust gas stream has not been standardised. As this level is set, some technologies will not have the ability to achieve the desired limits and others will prove too costly to implement. It is possible to remove 99% of $CO_2$ but from an economical standpoint it would not make sense. It should be noted that the target cleaning limits will be a balance between economical and technical issues.

The carbon capture technologies may require modification according to coal variability from different source mines. In addition to $CO_2$ capture ability, the $CO_2$ will need to be compressed and sequestered. Also, the ability to capture $CO_2$ comes at a cost to plant efficiency through large parasitic loads resulting in decreases of 6-10% percent.[24]

# 5. Types of $CO_2$ capture and control

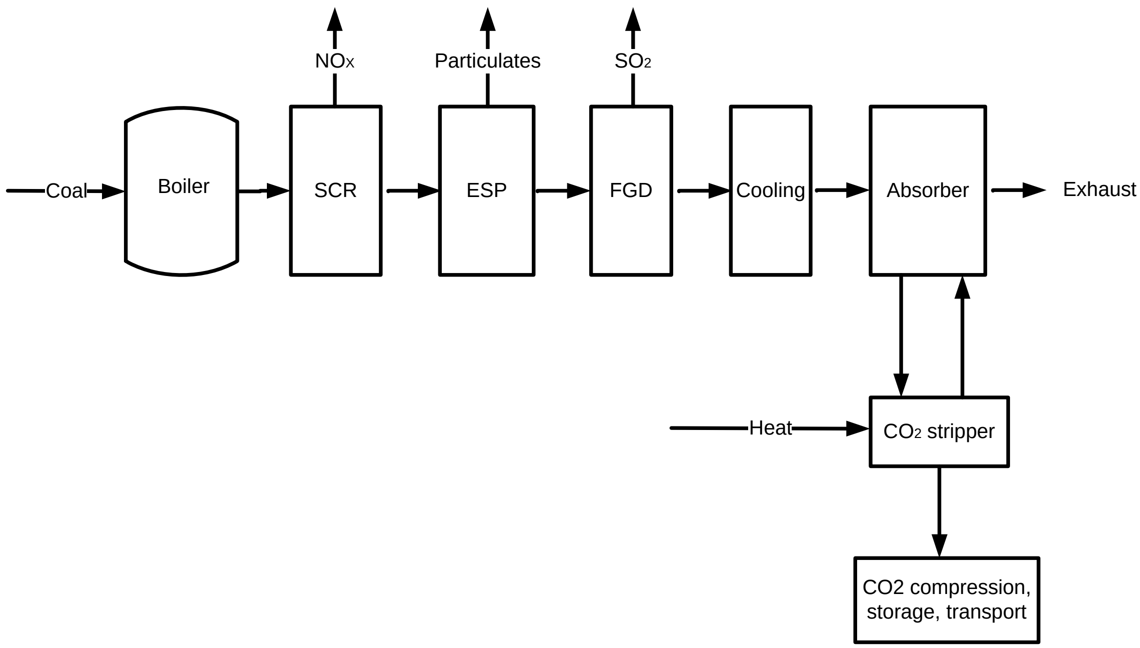
Carbon dioxide ($CO_2$) capture can generally be categorised as one of three types: (1) post-combustion, (2) pre-combustion and, (3) oxy-fuel combustion. Diagrams of these technologies are shown below and will be subsequently discussed further in detail.




## 5.1 Post-Combustion Technologies:

Post-combustion technologies involve the capture of $CO_2$ from the flue gas after combustion in the boiler. It generally involves a scrubbing process followed by a purification process resulting in the recovery of $CO_2$.

Post-Combustion $CO_2$ Absorption




Post-combustion $CO_2$ capture generally occurs during, or after, removal of other flue gas impurities. Proposed technologies include absorption, cryogenics, and membranes. Currently, chemical absorbers are the most common method of capturing $CO_2$ from flue gas. Current absorbents include using amine based solid sorbents, aqueous ammonia scrubbing, and aqueous ammonia multi-pollutant capture. Alkanol-amines are widely considered the most appropriate for use with post-combustion capture.[25] After combustion and prior to entering the chemical absorber, impurities must be removed from the flue gas to prevent contamination of the solvent. These impurities include $SO_X$, $NO_X$, particulates, etc. After removal of impurities, the flue gas is cooled and passed over an absorber where the $CO_2$ is chemically absorbed. The solvent is then transported to the $CO_2$ stripper where heat is added and a relatively pure stream of $CO_2$ is released and captured. This heat must be taken from the process steam impacting the low pressure turbine efficiency with further reduction in overall plant efficiency. The absorbent is regenerated by either an increase in temperature or by lowering the pressure. The absorbent is then returned to capture more flue gas $CO_2$ in a continuous process.

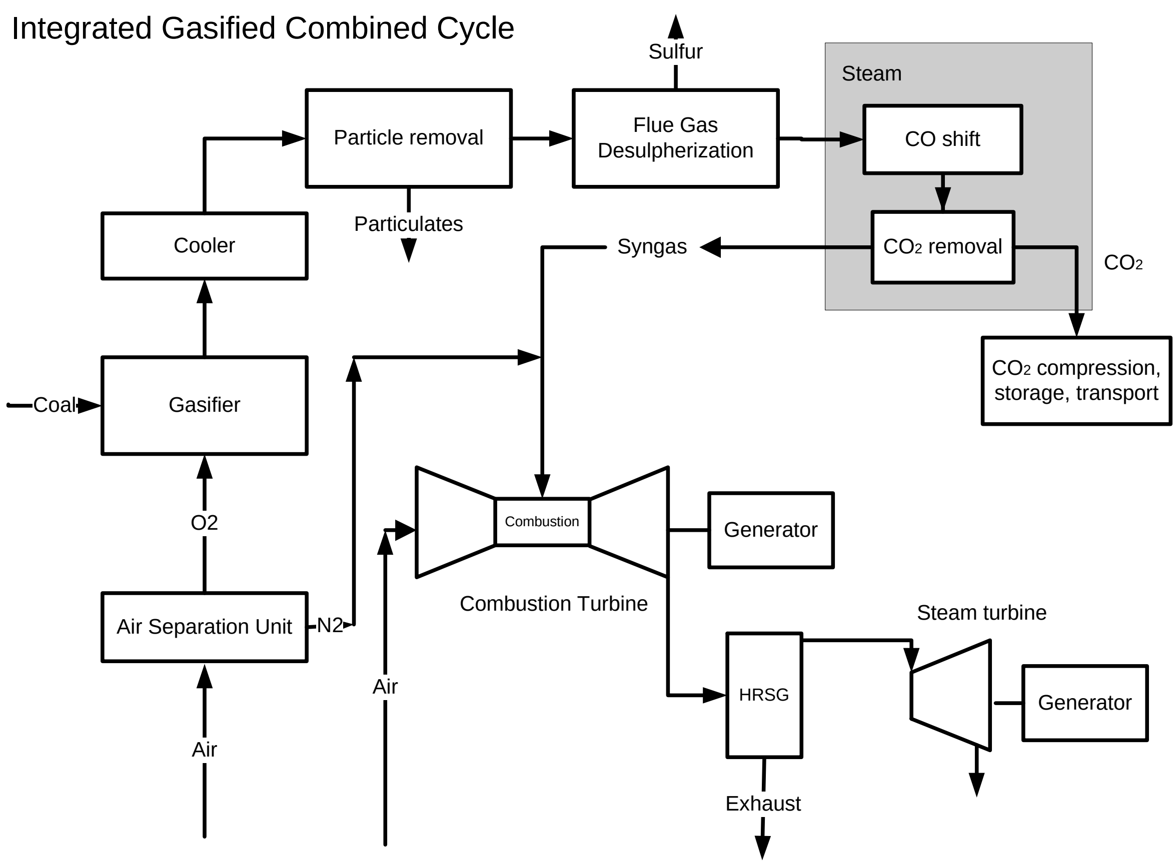
Some current coal plants can be retrofitted with these post-combustion, amine absorption systems. They can be applied to exhaust from both coal fired and natural gas combustion plants, as well as a variety of industrial plants. They can also be used in conjunction with other advanced technologies such as IGCC. Instead of stripping the carbon before combustion as is discussed later in this section, it can be captured post-combustion with this technology. The addition of post-combustion carbon capture technology is roughly estimated to double the footprint of an existing coal fired generating plant.

Alstom is currently undergoing an extensive test program on a post-combustion carbon capture plant in Pleasant Prairie, Wisconsin in the United States. This plant was built to test and demonstrate the technology's capabilities on actual flue gas. This system is predicted to capture over 90% of the $CO_2$ and also further eliminate residual pollutants such as $SO_3$. The absorber is based on chilled ammonia. It is anticipated this system will be operational before the end of 2011.

Powerspan, under a cooperative research and redevelopment program with the U.S. Department of Energy, is also developing a post-combustion regenerative process. It can integrate directly into its patented impurity system Electro-Catalytic Oxidation (ECO). The carbon capture addition is referred to as ECO2. It was designed to retrofit with existing coal fired plants. The $CO_2$ capture occurs after removal of $NO_X$, $SO_X$, mercury and particulates. The ammonia is used as a catalyst and is regenerated.

## 5.2 Pre-Combustion Technologies:

**Pre-combustion technologies involve the capture of $CO_2$ prior to fuel combustion.** Pre-combustion technologies typically refer to an Integrated Gasified Combined Cycle (IGCC) process. IGCC plants are generally coupled with natural gas steam reforming and use a water shift conversion to maximise hydrogen formation and $CO_2$ capture.



In principle, the individual components of the pre-combustion capture concept have been successfully used in the industry for many years. However, it still remains to be seen if this technology can be applied to power plants with acceptable reliability and availability in parallel with economic operations.[26] With the addition of the new complexity of $CO_2$ removal there is an even greater amount of uncertainty.

In pre-combustion technologies, the $CO_2$ is removed from the fuel by a reforming process, producing hydrogen. This hydrogen is then burned as a fuel in a combustion turbine. The advantage of the pre-combustion process is that $CO_2$ is captured in a richer $CO_2$ stream under pressure than in post-combustion processes. This results in an easier and less costly capture process. The disadvantage is that coal gasification costs much more than the cost to burn the fuel in a conventional power plant.

To maximise hydrogen and carbon dioxide formation a water-gas shift reaction occurs. This reaction combines gaseous water and carbon monoxide to produce $CO_2$ and hydrogen. $CO_2$ is then removed in the reforming process leaving a very hydrogen rich synthetic gas and $CO_2$ for capture. The chemical equation, simplified, is:

$$H_2O + CO \rightarrow CO_2 + H_2$$

**Integrated Gasified Combined Cycle (IGCC)**

IGCC is an integral part of the pre-combustion carbon capture technology and its progress is discussed in this section. It should be noted that the IGCC technology must become commercially viable before the carbon capture process of the plant is added.

IGCC power plants use hydrocarbon fuel, usually coal, and gasify it in a high pressure, high temperature environment. While in this gasifier, air or pure oxygen (taken from an air separation unit) is added. Pure oxygen is desirable, but not required, from an environmental standpoint, as it eliminates $NO_X$ emissions. The gas is called a synthetic gas (or syngas), and is cooled, cleaned of impurities, and used as a fuel in a combustion turbine. The hot exhaust gas from the turbine passes through a heat recovery steam generator (HRSG), producing steam to drive a steam turbine. Electricity is produced from both the combustion and steam turbines.

By removing the emission-forming constituents before combustion, an IGCC power plant produces very low levels of NOx, SOx, particulate matter and volatile mercury. IGCC by itself does not remove $CO_2$. $CO_2$ removal would be an add-on further increasing the cost associated with an IGCC facility when complying with potential $CO_2$ emissions regulations. Some estimates place IGCC plant costs 20% greater than their traditional counterparts, but costing 20% less over the long term. One advantage of pre-combustion carbon capture technologies is lower cost to remove carbon before combustion.

There are currently two commercial sized, coal based IGCC plants operating in the United States. The two U.S. projects were supported initially under the US DOE's Clean Coal Technology demonstration program, but are now operating commercially without government support. These two US projects along with two from Europe and one from Japan are discussed below.

The 262 MW Wabash River IGCC re-powering project in Indiana started up in October 1995 and uses the E-Gas gasification technology. This technology was acquired by ConocoPhillips in 2003.

The 250 MW Tampa Electric Co. Polk Power Station IGCC project in Florida started up in September 1996 and was based on Texaco gasification technology which is also known as Partial Oxidation Technology ($PO_X$). This technology was acquired by GE Energy in 2004. One fifth of the project's $600M capital cost was paid for by the US DOE as part of the Clean Coal Technology Program.[27] The project uses a 192 MW gas turbine, HRSG and a 123 MW steam turbine for a gross output of 315 MW. With a plant parasitic load of 10 MW and an additional 55 MW for air separation, the net output is 250 MW, approximately 20% reduction.

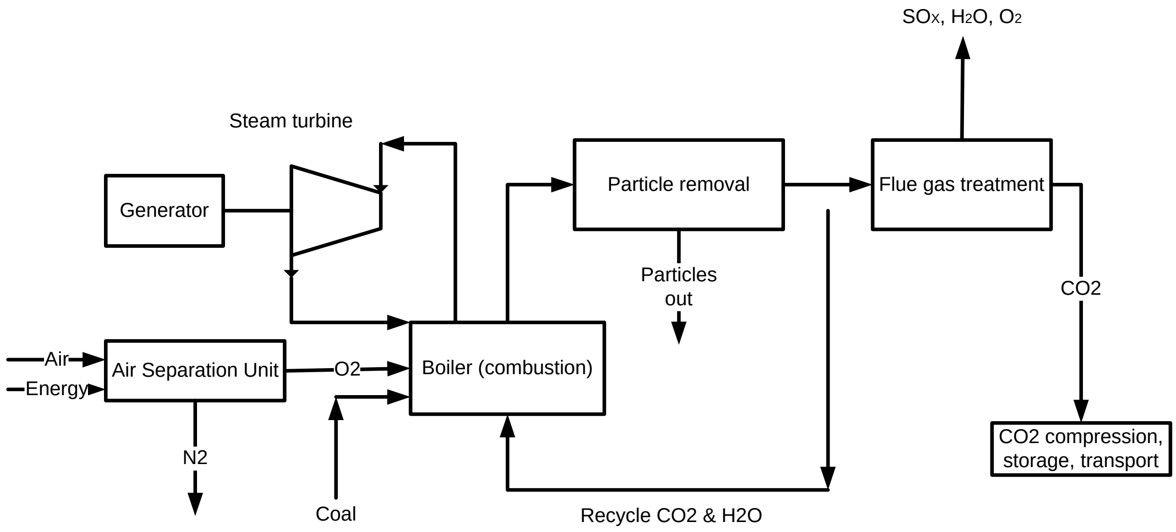
IGCC development also continues in Europe with, for example, the following operational plants. The first of the European IGCC plants was the NUON (formerly SEP/Demkolec) project in Buggenum, the Netherlands, using Shell gasification technology. It began operation in early 1994. The second European project, the ELCOGAS project in Puertollano, Spain, uses the Prenflo (Krupp-Uhde) gasification technology and started coal based operations in early 1998. In 2002, Shell and Krupp-Uhde announced that henceforth their technologies would be merged and marketed as the Shell gasification technology.[28]

IGCC development is also ongoing in Japan where a consortium of Japanese corporations and regional utilities joined to create an IGCC project utilising technology from Mitsubishi Heavy Industries Ltd. It uses a pulverised, air blown, two stage, entrained bed coal gasifier and a dry coal feed system. Their studies concluded that air blown gasifiers are better suited for commercial production than oxygen blown because they do not require an air separation unit (source of oxygen) which has an extremely heavy parasitic load. Unfortunately, this results in a very high level of nitrogen in the Syngas which makes it more difficult to remove carbon using pre-combustion technology.[29]

## 5.3 Oxyfuel Technologies:

In the oxyfuel process, coal combustion takes place in an oxygen rich (little to no nitrogen) atmosphere resulting in an exhaust which is primarily $CO_2$ and $H_2O$. The water can be easily condensed out leaving relatively pure $CO_2$ for capture.

Oxyfuel combustion capture




Oxyfuel combustion involves the combustion of coal in an environment of pure oxygen rather than nitrogen rich air. This results in a $CO_2$ purity level estimated at 95%. To accomplish this, an air separation unit is utilised to provide pure oxygen to the boiler. However, this process requires high levels of energy and negatively impacts the overall efficiency of the power generation facility. In the boiler, oxygen, coal and recycled exhaust gases are fed into the boiler at near stoichiometric conditions to generate steam for a steam turbine generator. After combustion, particles are removed from the flue gas and a portion of the exhaust gas is re-circulated to control temperatures in the boiler, and/or dilute the oxygen.[30] The remainder of the exhaust gas stream is treated to remove additional contaminants that were part of the coal feedstock and the water is condensed out. This leaves $CO_2$ for capture. The final removal of contaminants may take place simultaneously with $CO_2$ compression.

An advantage of this system is that NOx is not formed by combustion air and therefore it does not need removal from the exhaust gas stream. However, small amounts may be present from the feed stock (coal) constituents. Disadvantages include complexity of maintaining an oxygen pure environment for burning coal and the energy penalty associated with the oxygen separation process. These processes have parasitic loads up to 25%.

Oxyfuel technologies utilise a familiar, well proven, and commercially available pulverised coal configuration. Theoretically it can be retrofitted to many existing Rankine cycle power plants but there are several technology challenges that must be overcome before realisation. These challenges include heat transfer studies with the new fuel source, prevention of air in leakage, fouling and slagging issues to name a few. Advantages over the post-combustion capture include flue gases consisting mainly of $CO_2$ and $H_2O$. This increases the $CO_2$ capture efficiency and cost-effectiveness. Any impurities in the exhaust gas can be easily removed during the $CO_2$ compression stage, whereas post-combustion capture technologies based on solvent scrubbing technology require very clean exhaust gas.[31]

The German company Vattenfall is constructing an oxyfuel combustion pilot plant in mid 2008 in Brandenburg, Germany. It will be the first ever pilot unit in the world for a $CO_2$ free lignite fired power plant operating with the oxyfuel technology. The Vattenfall pilot plant will use this technology in conjunction with carbon storage for an approximate 30 MW power block. It represents the first step in testing the overall process for a meaningful capacity output and will provide proof that a large scale technological application of the method is feasible. After three years of testing and data collection, the information gained from this test will be utilised to plan a demonstration power plant of 250 to 300 MW capacity. These are estimated for completion between the years 2015-2020. The focus will be on optimising the overall process efficiency, evaluating profitability, and planning for a power project of approximately 1,000 MW capacity.

Vattenfall selected the oxyfuel method because it can build on power plant components already in use as well as additional components that have been extensively developed technically, such as air fractionation by combusting the dried pulverised lignite in an oxygen carbon dioxide atmosphere. The processes occurring in the boiler are not comparable to those with conventional combustion using normal air. For this reason, the pilot unit operations should test the combusting performance especially so as to optimise it for use in large scale power plants. In addition, emphasis is also being placed on analysing the material requirements, the availability of units, the $CO_2$ purification levels required and calculating the expected investment and operating costs.

The oxyfuel firing technology is still unproven and is not operating on any commercial scale. American Electric Power (AEP) and B&W teamed at the B&W Alliance Research Centre with several utilities for a 4$^{th}$ quarter 2007 demonstration. A full scale target retrofit of an existing AEP facility is planned between 2013 and 2015.

With the lack of a full scale operational oxyfuel technology facility, this technology is not expected to be commercially available for many years.

## 6. Insurance concerns with $CO_2$ free power plants

There are many concerns with the $CO_2$ free power plant. For now, these concerns are primarily speculatory in nature because the technologies have not made the leap to large scale power generation applications. As such, the following items are highlighted as potential areas of concern as technology moves to demonstration plant and commercial realisation.

**Technology:** The technologies are new and there are few units in operation. Portions of the new facilities must be considered unproven or even prototype. To date, only demonstration plants are in operation or scheduled for development.

After these demonstration plants become operational and data is gathered there will be another level of engineering to refine the project for full scale implementation. Only after full scale projects are operational can it be considered commercially available.

Insurance companies will be challenged to have qualified experts available to perform third party evaluations to determine the adequacy of the new technology designs. Also, the transfer of knowledge will be slow. With few operating locations and the variation in technologies it will be difficult to share experiences between owners and insurance companies.

**Human Element:** There will be an increase in plant complexity and personnel associated with the carbon capture technology thereby increasing the opportunity for human element issues. These include staff training, qualified personnel, procedures, and maintenance to name a few. There will be a subsequent increase in the associated O&M cost with the new facility.

**Scale-up:** Scale up and integration of components will be an issue, specifically with components like air separation units; coal dehydration; boilers with $O_2$ and $CO_2$ recycle combustion; desulphurisation plants; $CO_2$ purification; $CO_2$ dehydration and $CO_2$ compression. While not insurmountable issues, scale up of existing equipment always provides new challenges and will increase the risk of failure. Membrane technology and the scale up of sizes required for $CO_2$ capture from large power plants appears to be a significant technology challenge and may also prove problematic. The systematic process of scale up from pilot plant to demonstration plant to small commercialisation is essential for success.

**Business Interruption:** What will be the business interruption loss following failure of $CO_2$ capture? What value will this capture have? If the $CO_2$ capture portion of the plant does not function will the entire facility have to shut down to meet environmental permits thereby increasing the business interruption loss beyond the carbon capture portion to a loss of generation capacity? A complete understanding of the legislative issues and requirements will be needed to properly underwrite carbon capture facilities.

**IGCC Technology:** IGCC technology will need to be further developed for pre-combustion technology to advance. Therefore, new IGCC plants will need to be developed with a stabilisation of the technology to minimise the increased risk with pre-combustion technology carbon capture. Additionally there will be challenges associated with the hydrogen rich fuel for use in combustion turbines. In order to maximise overall plant efficiency the most advanced combustion turbines will be utilised which generally are not designed for this fuel source. This will provide another consequential area of increased risk associated with carbon capture technology.

Low pressure steam will also be required for solvent regeneration which will put additional requirements on the steam system. This may require modification or a new design for the LP turbine section of the steam turbine.

**Oxyfuel Process:** The oxyfuel process will require modifications of boilers and burners to accommodate the new process. Retrofit is possible but it would require extensive heat transfer studies to ensure the new fuel source would be acceptable in the existing boiler. There will be concerns with slagging and fouling associated with the new fuel source and there will be a very significant challenge keeping the boiler air tight during operation to prevent the influx of air (nitrogen).

Air separation units will also provide a challenge as the largest in operation today could only support a 300 MW facility.[32] This makes the scale-up of the air separation unit another area of risk.

**Corrosion & Environmental Concerns:** Will the new facilities produce additional environmental pollutants via methanol or amine emissions? Will corrosion issues remain a concern based upon the solvent used for $CO_2$ reduction? These questions will remain unanswered until the technology further advances.

The new generation of $CO_2$ free power plants will be introduced in highly efficient plants with steam temperatures reaching 700 °C (1292 °F). These increased temperatures will not impact the carbon capture process but the overall plant will have material problems that may significantly increase the risk.

**Vessels:** Will the necessary vessels be made of glass fibres leading to additional fire exposure? Will there be additional exposure due to flammable operating materials as washing solvents, methanol, amines etc.? Again, these questions will remain unanswered until the technology further advances.

**Compression, Storage & Transportation of $CO_2$:** Compression, Storage and transportation of $CO_2$ will post a large array of technical and logistical issues that are not addressed in this paper. However, it's worth noting that these issues alone may prevent the proliferation of carbon capture technology.

## 7. Conclusion & Outlook

Electrical usage across the globe is expected to increase and to meet this demand coal will make, and will have to make, a considerable contribution in the future. With a reserve of approximately 230 years at the current rate of consumption, coal is the fossil source of energy which will be available in the world for the greatest length of time. The route often put forward by environmental protection organisations of first relying on gas-fired power stations and then, in about 20 years, meeting the energy requirements by means of renewable energies does not seem realistic either economically or technically. Further development of renewable energies must of course continue but without abandoning further development in the burning of coal to generate electricity.

Burning coal, because of its chemical composition, releases about twice as much $CO_2$ per energy unit when compared to natural gas. This disadvantage can only be compensated for by (1) an increase in the level of efficiency of coal fired power stations and (2) $CO_2$ separation (carbon capture) from pre-combustion, post-combustion or oxyfuel technologies by means of economic large-scale procedures.

The technology associated with $CO_2$ capture is still in the development phase and there are many possible solutions that are still being tested. The final technologies will need to be profitable on a cost/kWh basis when compared with other clean energies; the demonstration plants will need to move to commercial scale deployment; international mutual consent about measures identified to address climate change must be agreed, i.e. subsidisation; and the sequestration issues must be overcome.

While these technologies are being developed, they will not be commercially available in US and/or Europe for large scale power stations (> 500 MW) for approximately 10 years, between 2015 and 2020. In the construction of new coal fired power stations, particular attention should be paid to making it possible for these to be retrofitted with equipment for $CO_2$ separation.

There will be an increased risk for insurance companies because of the higher cost associated with facilities constructed with $CO_2$ capture technologies and because of the necessary rapid technology deployment both for highly efficient coal fired power stations and for $CO_2$ separation. However, insurance companies have a history of addressing the evolutionary risk coverage needs of our clients. Examples include the development of flue gas cleaning plants, advanced gas turbines, and renewable energies.

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