Capture-Ready Coal Plants - Options, Technologies and Economics

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Abstract
This paper summarizes the spectrum of options that can be employed during the initial design and construction of a both pulverized coal and integrated gasification and combined cycle plants to reduce the costs and derating of retrofitting for CO_2 capture at some later date in the future. The impacts of these investments on the economics and lifetime CO_2 emissions of the plant were also investigated and quantified. A full report of the results of this analysis will be available over the Internet in the summer of 2006 [7].

Introduction
Interest in the construction of coal-fired power generation has increased significantly in recent years, sparked by continually increasing demand for electricity, combined with volatile prices of other fossil fuels, including natural gas and oil, the difficulties surrounding the construction of nuclear facilities, and the current challenges of availability and pricing of alternative generation technologies, such as solar and wind. In the United States alone it is expected that overall electricity demand will increase from 3,650 billion kilowatt-hours in 2002 to over 5,500 billion kilowatt-hours in 2025 [1]. This correlates into approximately 250 GW of new generation capacity.[1] Of this new capacity, the EIA estimates that 80 GW will be met through the construction of coal-fired plants. This corresponds to an average construction rate of eight 500 MW coal-fired plants per year over the next twenty-five years.

While coal-fired power plants offer significant cost and energy security advantages, they are also major sources of greenhouse gas emissions, namely CO_2. With an expected lifespan of 40 years or more, these plants will account for a significant portion of future global rises in greenhouse gas concentrations if no actions are taken to capture the CO_2 from these plants. However, this problem can be potentially mitigated if during the initial design and construction phase the plant is designed to be 'capture-ready':

A plant can be considered 'capture ready' if, at some point in the future it can be economically retrofitted for carbon capture and sequestration and still be economical to operate.

The concept of 'capture-ready' is not a specific design; rather it is a spectrum of investments and design decisions that can be made. Capture-ready coal plants have been identified by policy makers as an option for mitigating the long-term emissions of greenhouse gasses. This was recognized by members of the G8 nations at the 2005 Gleneagles Conference on clean

[1] Assumes an average 85% capacity factor for new plants

energy and sustainable development. In their plan of action, released at the conclusion of the conference, the members identified that the "acceleration of the development and commercialization carbon capture and storage technology" should be pursued by "investigating the definition, costs and scope for 'capture ready' plant and the consideration of economic incentives" [2]. This paper makes a start at sorting out the options, technologies and economics of capture-ready coal-fired power plants.

Options for reducing CO_2 emissions from coal-fired power plants
Several options are available to power plant owners to reduce emissions from fossil-fuelled plants, each having different investment and performance trade-offs. For coal, these options include:

- The construction of high-efficiency plants. This includes IGCC with advanced heat recovery, or ultra-supercritical PC plants, reducing the emissions of CO_2 per MWh up to 40% as compared with the average existing coal-fired power plant[2].
- The construction of plants now with carbon capture and sequestration technologies, reducing emissions of CO_2 per MWh by up to 90%.
- Rebuilding of existing plants at some point in the future to capture CO_2 emissions, or to use less CO_2-intensive fuels such as natural gas, or CO_2-free technologies such as nuclear, wind or hydro.
- The construction of 'capture-ready' coal-fired power plants, which accommodations are made during the initial design phase to reduce the cost and performance penalty of retrofitting CO_2 capture at a later date.

Choices for capture-ready plants
Some of the issues that face owners considering retrofitting their plants for carbon capture and sequestration include:

- Capital costs and the associated financing of the capture equipment
- Large reduction in the net output of the plant
- Increased operation and maintenance costs
- Increased total and dispatch cost of electricity (COE)
- Location and access to a suitable sequestration site
- Timing and length of the downtime required for the retrofit
- Physical space for new equipment

The issues surrounding the retrofitting of these plants are significant, and the suitability for retrofit for each plant would have to be evaluated independently, as some of these factors would be larger in magnitude, or have greater impacts for some plants compared to others.

Pulverized Coal with Post-Combustion Capture
While no major technical hurdles exist for retrofitting PC plants with post-combustion (MEA) capture, the expected derating, capital requirements and increase in operation and maintenance costs are expected to pose significant challenges to owners and policymakers if and when actions are taken to reduce CO_2 emissions from these facilities. Some of the issues that are specific to retrofitting PC plants with post-combustion capture include:

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[2] Assumes a fleet average efficiency of 33%, new build efficiency of 46% (HHV)

- A 20-30% reduction in the electrical output of the steam turbine/electrical generator, due to the diversion of significant amounts of low-pressure steam to the reboilers of the MEA CO_2 recovery system [3].
- The low-pressure stage of the steam turbine may need to be rebuilt in order to be able to handle the lower low-pressure steam availability, unless additional steam is provided from an alternative source.
- The stringent sulfur level limits of the MEA solvent, which may require an upgrade of the existing flue gas desulfurization equipment.
- Additional space requirements for the CO_2 recovery and compression system, which may cause difficulties for existing plants that do not have space readily available.

Pulverized Coal with Oxyfired Combustion Capture
Less operational experience exists with oxyfired PC plants, but studies indicate that the oxyfired technology may have capital cost and efficiency advantages over post-combustion capture. Some of the issues specific to the retrofitting of PC plants with oxyfired combustion capture include:

- Significant changes are required to the air handling system as a flue gas recycling system will be required in order to keep the temperatures and heat transfer properties of the combustion gasses within the operating range of the boiler.
- Boiler air leakage can dilute the flue gas to unacceptable levels, and the boiler may require modifications to minimize the levels of air infiltration.
- The power requirements of the air separation unit, which can consume up to 20% of the generator output [3].
- Additional space requirements for the air separation unit, flue gas non-condensables removal system, and the CO_2 compression and drying equipment.

The capture-ready options for PC plants are relatively limited, but some steps can be taken to reduce impacts of a retrofit on the capital requirements and derating of the plant. These include:

- The pre-investment in a high-efficiency supercritical or ultra-supercritical boiler, which would reduce the amount of CO_2 being produced by the plant and correspondingly reduce the capital costs and energy requirements of capture equipment, and the derating of the plant.
- Leaving extra space in appropriate places for the capture equipment.
- Ensuring that the plant site is located close to an appropriate sequestration site, and the required easements for a CO_2 pipeline system is available.

Integrated Gasification/Combined Cycle (IGCC)
IGCC technology offers advantages over PC plants for CO_2 capture as the CO_2 can be separated at higher partial pressures, reducing the amount of capital required and the energy penalty for capture. Less operational experience exists with IGCC plants, however and they are more complicated to operate and construct than a traditional PC plant. Some of the issues that are specific to retrofitting IGCC plants for CO_2 capture include:

- The water-gas shift reaction of the syngas and CO_2 removal reduces the heating value of the syngas by approximately 15%, which would cause a derating of the combustion turbine [4].
- The convective and radiative gas coolers may no longer be required, as the addition of steam for the water-gas shift reaction may sufficiently reduce the temperature of the syngas.
- The acid gas removal system would require the addition one more stage required to remove CO_2 in addition to H_2S. MDEA system (if present) may need to be removed and replaced with 2-stage Selexol-type acid gas removal system.
- The combustion turbine combustors may need to be changed and blade retrofit may be needed in order to operate on hydrogen gas.
- Compressed air for the air separation unit may no longer be available from the turbine, necessitating the addition of a parallel air compressor.
- Re-arrangement of existing equipment may be required to accommodate the addition of the water-gas shift reactors, second acid gas removal stage and CO_2 compression and drying equipment.

The capture-ready options for IGCC plants have been more widely explored, and several opportunities exist to reduce the derating and capital costs of a retrofit. These options include:

- The pre-investment in over-sizing the gasifier and air separation unit, to ensure that sufficient hydrogen can be produced to maintain full loading of the turbine, reducing the derating of the plant.
- The selection of a high-pressure gasifier design, which would reduce the energy requirements of the CO_2 compression equipment.
- The selection of a water quench gas cooler, which eliminates the capital in gas coolers that may be stranded after a retrofit.
- Leaving extra space for the addition of the water-gas shift reactors, second acid gas removal stage and CO_2 compression and drying equipment
- Ensuring that the plant site is located close to an appropriate sequestration site, and the required easements for a CO_2 pipeline system is available.

Economics of capture-ready plants

The construction of capture-ready plants will only be economic with regulations or taxes in place to mitigate CO_2 emissions. Sekar et al [6] performed an NPV analysis to determine the CO_2 tax levels and growth rates that would be required in order to justify building IGCC plant, which is more expensive to build and operate than a PC plant, but less expensive to retrofit for CO_2 capture. The results of this analysis were then plotted against a range of benchmark future carbon tax regimes published in the literature.

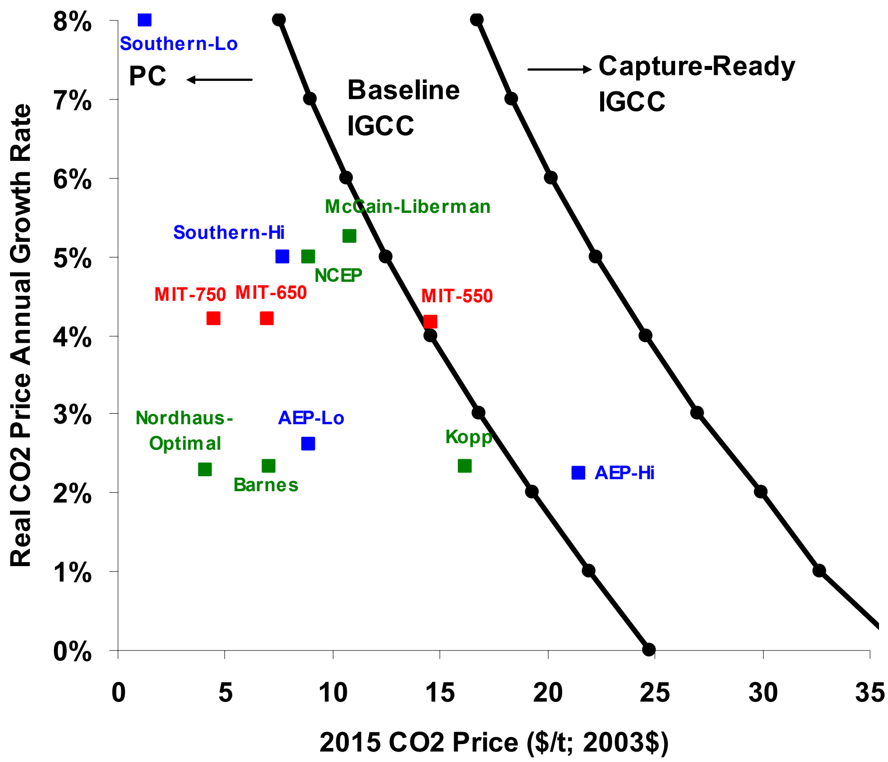
This paper has expanded upon this analysis to include the option of building a capture-ready IGCC plant in addition to a baseline plant, based on data from the EPRI phased construction report [4]. Table 5 lists the economic parameters of the baseline and capture-ready plant used in this analysis, and Figure 1 illustrates the results of this analysis, and the original analysis performed by Sekar et al.

Table 5 Comparison of capital and operational costs for 500 MWe IGCC plant with and without pre-investment

Technology Choice	Baseline IGCC	IGCC with pre-investment (capture-ready)
Before retrofit		
Investment (M$)	590	620
O&M cost (M$)	22.1	22.5
Fuel cost (M$)	50.7	50.7
CO2 released (MT)	3.2	3.2
After retrofit*		
Retrofit Investment (M$)	244	175
O&M Cost (M$)	29.8	28.3
Fuel Cost (M$)	60.2	60.4
CO2 Released (MT)	0.4	0.4
CO2 Captured (MT)	3.4	3.4

* includes incremental costs of building and operating a makeup power plant to maintain output constant at 500 MWe

Figure 1 Benchmark future carbon tax regimes vs. optimal technology choice



Impact of capture-ready on lifetime CO_2 emissions

In addition to the impact on the NPV costs of the plant, building capture-ready plants also has a marked impact on the lifetime CO_2 emissions from a facility. Capture-ready plants are less expensive to retrofit, and incur a smaller derating than a non capture-ready plant. These factors reduce the carbon tax level at which a retrofit is economically justified which moves up the retrofit date by several years, significantly and reduces the lifetime CO_2 emissions of a power plant. As an illustration of this impact, Figure 3 shows the retrofit year and Figure 4 illustrates lifetime CO_2 emissions for a range of initial carbon tax scenarios. Further discussion of the methodology and assumptions used in this analysis is upcoming in [7].

Figure 2 Impact of technology choice on retrofit year (CO_2 tax growth rate of 5%)

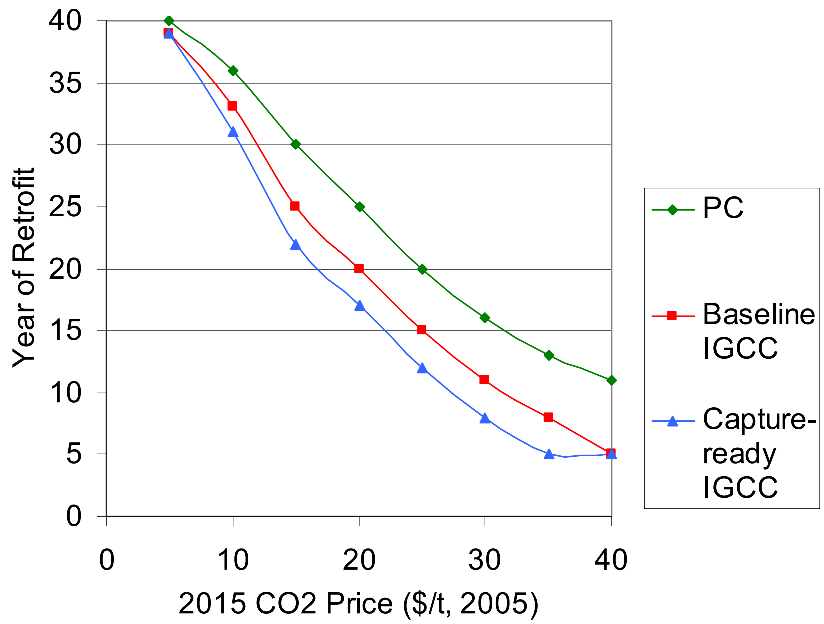
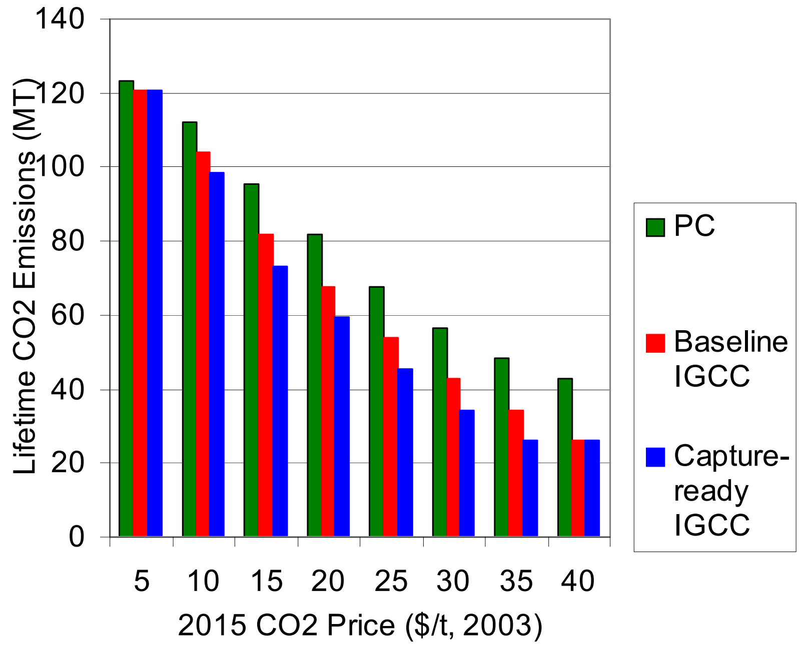


Figure 3 Impact of technology choice on lifetime CO_2 emissions (CO_2 tax growth rate of 5%)



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