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Carbon capture retrofit options with the on-site addition of gas turbine combined heat and power cycle

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Abstract

This article examines the economic factors that may be important in determining the overall performance of coal plants retrofitted with an additional gas turbine combined heat and power cycle. A comparison is made with an integrated retrofit where steam is extracted from the power cycle.

Retrofit, post-combustion capture, coal plant, gas turbine

1. Introduction

The energy penalty for post-combustion capture from can be minimised - independently of the intrinsic energy of regeneration of the solvent used – by effective thermodynamic integration with the power cycle. For coal plants, a range of integration options with the power cycle are possible for new build plants [1]. For existing plants full integration of the capture system with the power cycle may result in thermodynamic losses. Alternative retrofit options for good performance with capture are possible, but they entitle either a capital-intensive steam turbine retrofit or the addition of let-down turbines [2]. It is, however, not uncommon that the power cycle of an existing coal plant lacks the necessary space for access and that the turbine hall foundation may not be able to support additional turbines.

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Even when a retrofitted post-combustion capture system could be fully integrated with the existing power cycle, the electricity output from a site retrofitted with capture will still be reduced. This is still likely to leave the alternator and/or switchgear and grid connection capacity on the retrofitted site underutilised. Either the lost revenue from electricity sales, or the additional investment and running costs for the new capacity (with CCS) necessary to compensate for this loss of output, need to be taken into account as a minimum. As an alternative, if a capture retrofit to an existing plant can be combined with the on-site addition of a natural gas turbine combined cycle plant to provide heat and power to run the capture system, the site power output can be maintained, or even increased, and the need for replacement power avoided [3]. There is also more flexibility to achieve effective integration, since the new gas turbine combined cycle can be designed to integrate closely with the capture equipment for the existing plant and for itself.

This paper examines the economic factors that may be important in determining the overall performance of coal plants retrofitted with an additional gas turbine combined heat and power cycle. A comparison is made with an integrated retrofit where steam is extracted from the power cycle.

2. Retrofitting existing coal plants with an additional fuel source

The addition to a pulverised coal boiler of a separate natural gas ancillary boiler to provide steam for solvent regeneration by burning natural gas at a relatively low temperature was initially proposed by Singh et al [4].

The drawback of using a separate boiler to provide the energy for solvent regeneration is obvious. Great efforts have been deployed to improve the thermal efficiency of CCGT plants, currently up to around 60% LHV, because it makes economic sense to do so. The calorific value of the natural gas is first used at very high temperatures in the gas turbine, then high pressure, high temperature steam is raised from the gas turbine exhaust. Most of the energy coming from the fuel is used and low grade heat is rejected in the gas turbine exhaust at around 80-100ºC and in the steam cycle condenser at around 30ºC. Providing energy for solvent regeneration in a steam extraction retrofit by extracting low pressure steam from the turbines repeats the above, only differing in the temperature of condensation. The steam required for capture is condensed in the solvent reboiler at temperatures ranging from 100ºC to perhaps 150ºC, depending on the solvent used. In contrast, separate ancillary boilers do not make use of the full potential of the fuel calorific value. They turn the energy in the gas to heat at this same low reboiler temperature, missing out all the opportunity to extract higher-grade electrical energy.

The marginal efficiency of the additional power compared to a new-build gas plant with CCS is an appropriate metric to measure the effectiveness of the additional gas consumption. It is respectively 12% LHV for a separate boiler heat-match retrofit providing the heat necessary for solvent regeneration, and 32% for a separate boiler with a let-down turbine for a heat and power matched retrofit where the let-down turbine also provide the electricity for CO2 compression and capture ancillaries equipment [5]. It can be contrasted to the option of making up power losses by burning the fuel in a separate CCGT unit elsewhere. Unsurprisingly, Singh et al report higher cost of abatement for post-combustion capture.

Separate ancillary boilers have more recently been proposed for natural gas plants retrofits in the UK for capture-ready feasibility studies as part of the plant permitting process. As a retrofit option, they offer a low-hassle approach to plant permitting, but can possibly lock existing sites to low performance with capture if the space requirements for more efficient alternatives are not met.

Retrofitting an existing coal with the addition of a gas turbine combine heat and power cycle offers a more capital-intensive and more efficient alternative. Bashadi [6] examined increasing the output of an existing coal plant and retrofitting with post-combustion capture with a series of options involving the addition of combined cycle gas turbines. Capture from the additional fossil fuel source was not considered.
The capacity of an existing site to export additional electricity when an additional fuel source is added is, in practice, likely to determine the size of the gas turbine to maintain the site output.
This has been proposed for several post-combustion capture retrofit projects on existing coal plants, e.g. the Pioneer project in Canada or the Longannet power station retrofit in the UK [7].

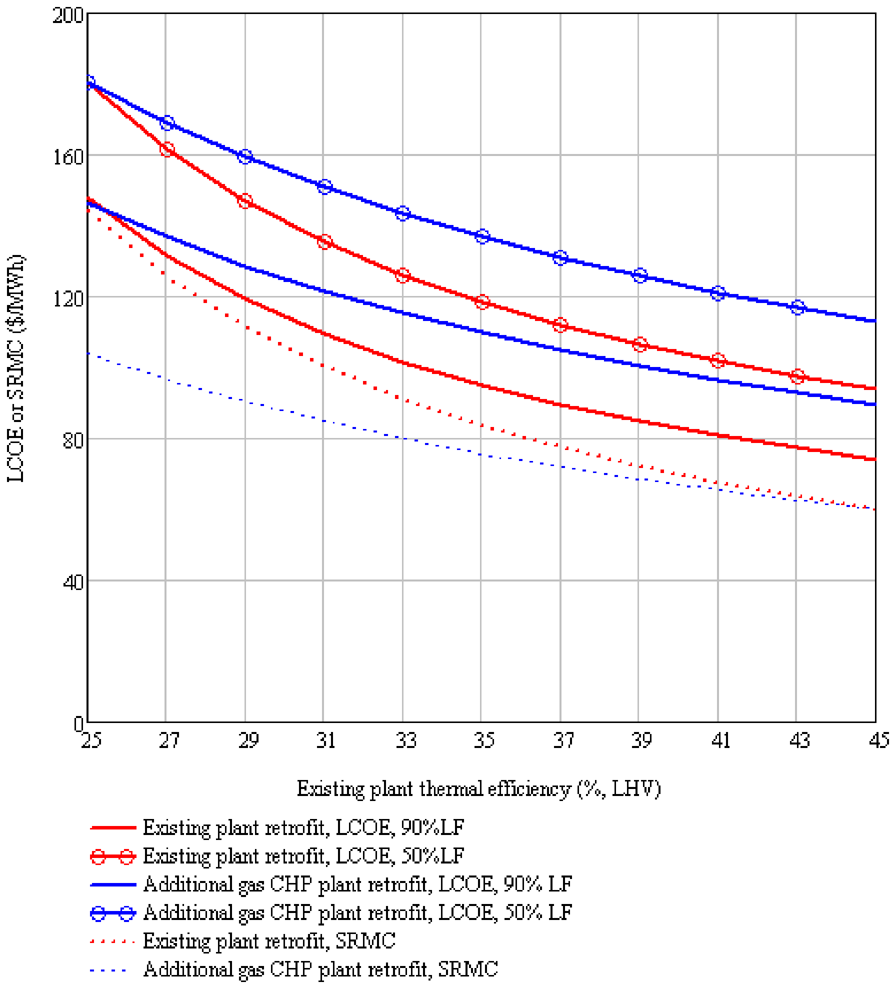

Figure 1: Variation in Levelised Cost of Electricity (LCOE) and Short-Run Marginal Cost (SRMC) for two load factors – Efficiency penalty of integrated retrofit: 12% point, attributed to unsuited steam cycle configuration Low gas price scenario 10$/MWh (2.9 $/MMBTU)

3. Relative economics of retrofit options

This section examines the drivers for the on-site addition of a gas turbine Combined Heat and Power (CHP) plant to an existing coal plant. The existing site output is maintained with the additional gas CHP plant. The additional CO2 emissions from the gas CHP plant are not abated, unless otherwise stated. For integrated retrofit with steam extraction, either the lost revenue from electricity sales, or the additional investment and running costs for the new capacity (with CCS) necessary to compensate for this loss of output need to be taken into account. It is assumed that make-up power is purchased from the grid at the levelised cost of electricity of a new-build gas plants with CCS.

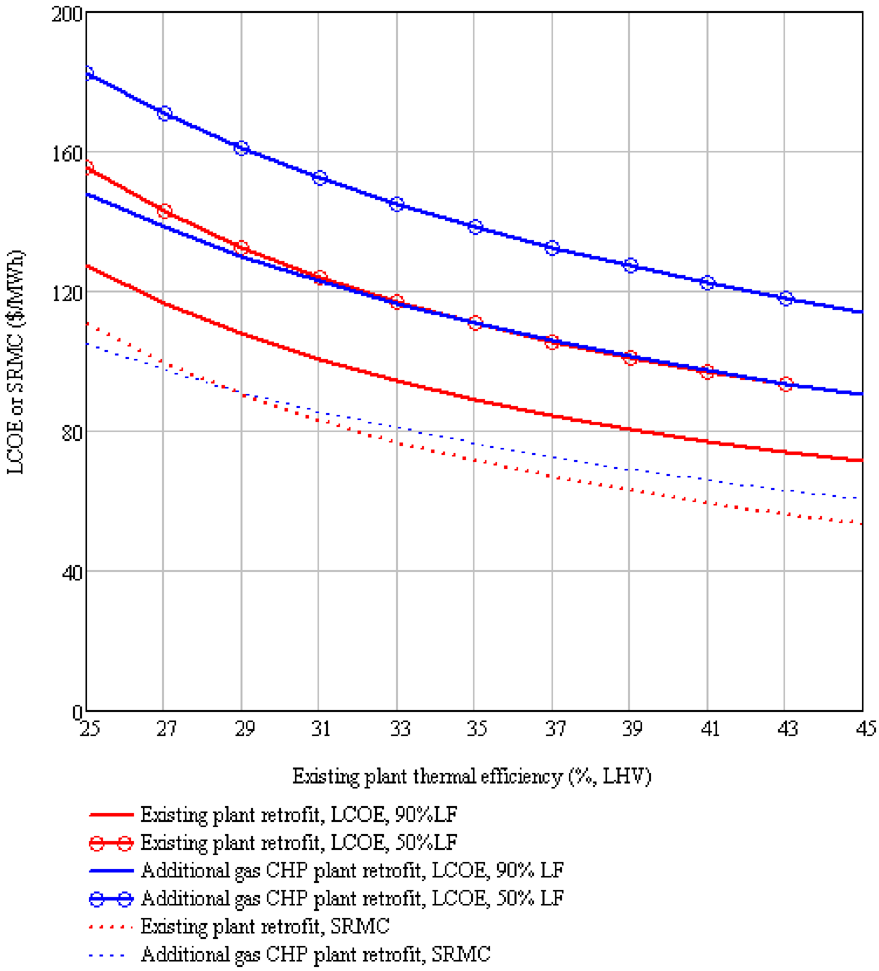

Figure 2: Variation in Levelised Cost of Electricity (LCOE) and Short-Run Marginal Cost (SRMC) for two load factors – Efficiency penalty of integrated retrofit: 8% point, for a capture-ready steam cycle configuration Low gas price scenario 10$/MWh (2.9 $/MMBTU)

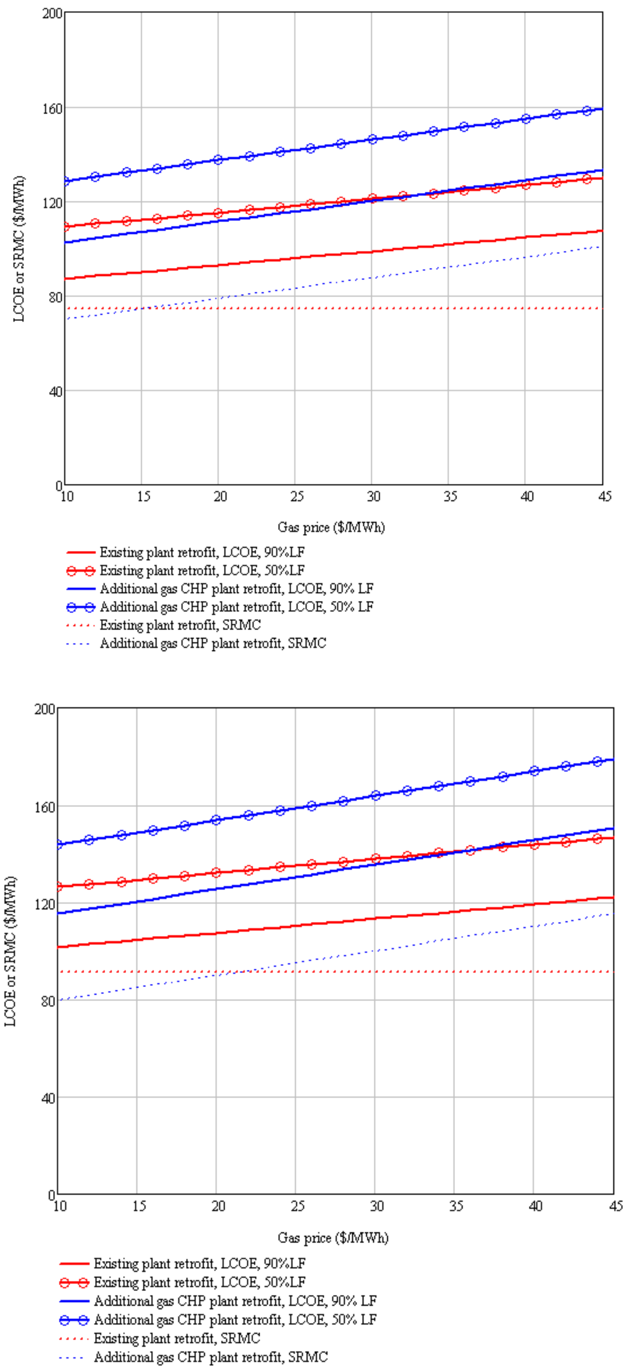

Figure 3: Variation in Levelised Cost of Electricity (LCOE) and Short-Run Marginal Cost (SRMC) for a range of gas prices, corresponding to 2.9 to 13.2 $/MMBTU. Top figure: existing coal plant efficiency 38% LHV, efficiency penalty 12% point. Bottom Figure: existing coal plant efficiency 33% LHV, efficiency penalty 12% point

3.1. Sensitivity to the existing coal plant thermal efficiency and to the steam turbine configuration

The existing coal plant thermal efficiency has a strong effect on the overall economics of a retrofit with capture. Integrated retrofits with steam extraction are more sensitive to variations of the thermal efficiency of the existing plant. This is illustrated in Figure 1 and Figure 2 for two scenarios with a respective efficiency penalty of adding capture of respectively 8 and 12 % point LHV, i.e. at the lower end and the higher end of possible retrofit configurations.

Previous work has shown that the efficiency penalty of an integrated retrofit with steam extraction from the steam cycle of a pulverised coal plant is strongly dependent on the configuration of the existing steam cycle [2]. If the steam turbines have been designed as capture-ready, performance with capture can possibly be close to that of new-build plant with capture from the start. Otherwise, it is likely that the pressure of the crossover pipe between the intermediate and the low pressure turbines, where steam is typically extracted for solvent regeneration, will not be suited to avoid thermodynamic losses. Typically, existing sub-critical plants have a single cylinder intermediate pressure turbine with an elevated outlet pressure, i.e. an elevated crossover pipe. Thermodynamic losses will be incurred when steam extracted from the power cycle has to be throttled down to the pressure required for the capture system. This can result in a significant increase of the efficiency penalty of a retrofit.

3.2. Sensitivity to fuel prices

Over a wide range of gas prices, it can be seen in Figure 3 that integrated retrofits have lower costs of electricity generation compared to retrofits with additional gas CHP plants.

The Short Run Marginal Costs (SRMC) of additional plant retrofits are only lower at low gas prices, representative of current US gas power generation prices in 2012, but Levelised Cost Of Electricity are higher (LCOE).

3.3. CO2 capture from the additional gas plant

It is unlikely that large scale decarbonisation of electricity generation can be achieved without CCS on emissions from gas power generation. Figure 4 illustrates the variation of SRMC for changes in carbon charges for an existing coal plant with a 33% LHV efficiency and a 12% point efficiency penalty with capture. This could possibly affect the operating hours of additional gas CHP plant retrofit operating without capturing the emissions from the gas plant at carbon charges around 30 $/tonne.

4. Other considerations

Certain limitations apply to the analysis presented here. Specific information about the market where the plant operates is necessary for a more detailed analysis of retrofit options. These limitations are discussed below, but have not been included in this work

4.1. Change in load factor

It is important to recognise that changes in short run marginal costs can possibly have an effect on the operating hours of a plant. A plant may be able to achieve a higher load factor because it has a lower short run marginal cost of generation than the alternative retrofit option. The electricity price during the additional period of operation cannot, however, be more than the SRMC of the alternative option that is assumed to be constrained off the grid. To allow for this increased running time the additional revenue need to be applied to reducing the LCOE for the plant considered for the period when both plants are operating, for a direct comparison.

4.2. Factor in residual value

The residual value of the additional gas CHP plant at the time that the existing coal plant would close can also be used to reduce the effective LCOE for the additional gas plant retrofit for comparison with the LCOE of the integrated retrofitted of an existing coal plant.

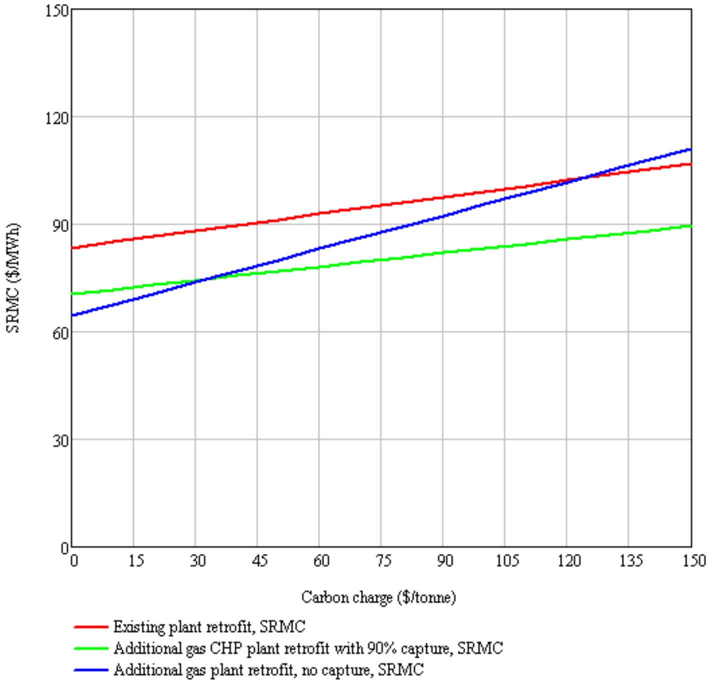

Figure 4: Variation in Short-Run Marginal Cost (SRMC) for a range of carbon charges without purchase of make-up power Existing coal plant efficiency: 33% LHV. Efficiency penalty of capture: 12% point

5. Considerations for capture-ready coal plants

Selecting capture-ready options in an era of rapid development of CCS, hence likely capture technology change before capture retrofit, is a challenging task. The main risk is that the plant will be locked in to an unnecessarily low level of performance with capture after improved technologies, such as better post-combustion solvents, become available. Technology lock-in can be prevented by avoiding a technology-driven commitment to a steam extraction pressure and flow rate for steam extraction. An additional gas

CHP plant retrofit, where the ancillary power for CO2 compression and other capture operations and some of the heat for regeneration (the remainder coming from the main steam cycle), avoids committing to a specific steam extraction and represents a credible alternative for a large fraction of the future global fossil fleet. These plants will not be expected to fit capture before a general CCS roll-out, and some of these plants may be retrofitted with radically different solvents from those available at the time they were designed.

It can be expected that making coal plants capture-ready for integrated retrofit with steam extraction and also for the addition of a separate CHP plant will increase the value of these new plants. It would do so by mitigating technology risk and by hedging against low load factors through a reduction of the costs of electricity generation at low gas prices.

Conclusions

Retrofitting existing coal power plants with the addition of a gas turbine combined heat and power cycle is an alternative option to integrated retrofit with steam extraction from the main power cycle. It has been previously considered for low-risk retrofit approach for low-efficiency paid off existing coal plants.

It appears, however, that over a range of fuel prices, electricity generation costs are higher than integrated retrofits, except at the lower end of gas prices typical of the US gas power generation market in 2012.

The additional CO2 emissions of the gas CHP were not proposed to be abated in recent projects where this option has been considered. This analysis show that moderate carbon charges may affect Short Run Marginal Costs if the gas CHP plant CO2 emissions are not abated. It also points out that it is possible to combine integrated retrofit options and additional gas CHP plant retrofit options for new capture-ready coal plants to lower exposure to reduced load factors over a range of fuel gas price scenarios.

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