

The Economics of Carbon Capture and CO₂ Emission Charges

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Abstract: This paper summarizes recent research examining the economics of carbon capture and storage (CCS) technologies for fossil fuel power plants. The main conclusion is that CCS technologies have the potential to be a powerful tool in reducing carbon dioxide (CO₂) emissions at a relatively moderate economic cost. CCS should allow the operators of fossil fuel power plants to limit the increase in electricity prices resulting from the adoption of a cap-and-trade system and the attendant mandate to obtain CO₂ emission permits. At the same time, the magnitude of current carbon emissions by fossil fuel plants, in particular those based on coal, implies that CCS can have a substantial moderating effect on the market price of emission permits. From a policy perspective, the most urgent implication of these findings is that currently known CCS technologies be certified for power plants on a commercial scale.

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It appears increasingly likely that the world's largest economies will adopt rules for reducing the emissions of carbon dioxide (CO₂). A cap-and-trade system is the leading mechanism for setting CO₂ emission limits and obtaining market prices for emission permits. At the same time, demand for electric power has been growing steadily across the world and is expected to continue to do so in the future. At present, there does not seem to be a credible scenario for satisfying the world's appetite for electricity in the foreseeable future - say the next 30 years - without relying to a significant extent on fossil fuels (see, for example, [1]). At 6 gigatonnes of CO₂ emissions, the U.S. share was about 25% of global emissions, with roughly 2 gigatonnes being emitted by coal-fired power plants and almost 1 gigatonne by natural gas plants. These magnitudes leave no doubt that fossil fuel plants will have a major part in determining the economic impact of impending CO₂ regulations.

The possibility of capturing CO₂ at fossil fuel plants by means of Carbon Capture and Storage (CCS) technologies has gained prominence in recent years. Several such technologies have been documented in pilot projects, including both pre- and post-combustion capture. Furthermore, a number of companies are currently seeking to show the feasibility of these technologies for power plants on a commercial scale (at least 500 Megawatt). In the U.S., one of the most prominent such efforts is the FutureGen project in Illinois which was shelved in 2008 but now seems destined for continuation, with partial funding provided by the Department of Energy. While the currently known CCS technologies still have to be certified for power plants on a commercial scale, the CO₂ abatement potential of these technologies is indisputable. For both coal-fired and natural gas plants, the adoption of CCS technology is expected to cut CO₂ emissions by 85-90% per kWh of electricity. In this context, it should be kept in mind that coal and gas start from very different base levels: absent any CCS capabilities, coal-fired plants currently emit about twice the CO₂ of natural gas plants per kWh of electricity.

A number of recent engineering studies have projected the cost increases associated with CCS capabilities. The adoption of such technologies will increase the variable operating costs, in part because CO₂ capture requires additional electricity consumption and because of the expenditures associated with CO₂ transportation and storage. In addition, the investment in new power plants with CCS capabilities entails a substantial increase in upfront construction costs. While there is some variation in the projected cost increases, the overall range is sufficiently compact so as to address the following interrelated questions with some degree

of confidence:

- In terms of CO₂ emission charges, what is the break-even price at which operators of fossil fuels power plants would find it advantageous to invest in CCS capabilities rather than buy emission permits on the open market?
- Assuming that the current CCS technologies can be certified for commercial size plants on the financial terms currently projected, how large an increase in electricity prices should be expected in response to alternative CO₂ emission charges?
- Will CCS capabilities have a tangible impact in keeping the expected market price of CO₂ emission permits within a certain range, say below \$60 per metric ton of CO₂ emitted?

Our study in [3] approaches these questions by taking the currently available engineering cost estimates associated with the adoption of CCS capabilities and making them the basis of an economic equilibrium analysis. To that end, it is essential to distinguish between alternative market structures for the supply of electric power. In many countries, including the U.S., electricity generation has traditionally been bundled with transmission and distribution, and prices for these services have been determined according to a Rate of Return (RoR) regulation scheme. Accordingly, electricity prices are set in each period so as to provide the regulated firm with a target return on its invested capital. When viewed over its entire lifetime, the firm will then make zero economic profits. For this scenario, the calculations in [3] are based on the presumption that, in response to CO₂ emission charges, regulatory commissions will instruct the utility to invest in CCS capabilities whenever that alternative becomes advantageous from the perspective of future discounted consumer surpluses.

As of today, a sizeable minority of states in the U.S. have deregulated the supply of power generation. The analysis in [3] therefore considers also a scenario in which utilities procure electric power in a competitive wholesale market and then distribute it to consumers. In equilibrium, the competitive wholesale price of electricity is given by the long-run marginal cost of power generation. In addition to current operating costs, this long-run unit cost also includes an annuitized share of the plant construction costs. Power generators are expected to adopt CCS capabilities for new power plants once CO₂ emission permits move beyond the break-even value, that is, CO₂ emission permits become sufficiently expensive so as to

push the long-run unit cost per kWh beyond the cost level that is achievable with CCS capabilities.

In connection with coal-fired plants, the estimates in [3] indicate that for the adoption of CCS technology a charge of approximately \$25 per tonne of CO₂ emitted is the break-even price. Thus power generators would find it advantageous to invest in CCS capabilities, provided CO₂ emission permits trade for at least \$25 per tonne. Consistent with earlier studies, we find that, concurrent with an investment in CCS capabilities, power generators would find it attractive to switch from traditional Pulverized Coal (PC) plants to so called Integrated Gasification Combined Cycle (IGCC) plants with CCS technology. Our estimates of the break-even price for coal are remarkably similar for the competitive and the regulated power supply scenario. A consumer oriented regulatory commission that seeks to optimize the trade-off between paying for emission permits and investing in more expensive plants with CCS capabilities will also view a CO₂ emissions price of about \$25 as the trigger value.

The expected increase in the retail price of electricity resulting from CO₂ emission charges are projected to be in the range of about 25-30%. These forecasts take into account that electricity generation contributes roughly 60% to the retail price of electricity (the remainder accounting for the cost of transmission and distribution). Once CCS adoption becomes advantageous, electricity prices will be quite insensitive to CO₂ emission charges beyond the break-even point. However, the dynamics of price increases will be different in the competitive as opposed to the regulated scenario. In a competitive market, prices reflect the forward looking marginal cost and therefore one would expect relatively rapid price adjustments in response to CO₂ emission charges. Under RoR regulation, in contrast, prices are based on historical cost and our findings indicate that the new equilibrium price for electricity would be reached only after 30 years. If utilities were to receive emission allowances for CO₂ emitted from older power plants constructed prior to the adoption of the cap-and-trade system (100% grandfathering), then electricity prices are projected to rise in almost a linear fashion over the 30 year time window. For other, partial “grandfathering” policies, electricity prices would increase more dramatically in the short-term.

Our analysis indicates that for coal-based plants the currently envisioned CCS technologies could make a substantial CO₂ abatement contribution at a relatively modest cost. In particular, some of the earlier projections showing a doubling of electricity prices in connection with CCS appear too dire. We also come to a more optimistic conclusion than the

McKinsey study in [2, page xiii], which puts the marginal cost of CO₂ abatement via CCS technology at coal-fired power plants near \$45 per metric ton. Of course, the equilibrium price of emission permits will depend not only on the reduction in emissions but also on the time frame for achieving these reductions. Since coal-fired plants presently account for about 20% of all CO₂ emissions (approximately 8 gigatonnes) worldwide, the availability of CCS technology, once fully proven, could also be a major consideration in weighing the need for “safety valves” in connection with a cap-and-trade system (the government would commit to issuing additional permits if emission prices were to exceed a certain threshold).

For natural gas power plants, the analysis in [3] predicts that the adoption of CCS capabilities would become advantageous only if CO₂ emission charges traded for at least \$60 per tonne. The reasons for this substantially higher break-even price are that (i) natural gas emits only about half as much CO₂ as traditional coal plants per kWh and (ii) the percentage increase in plant construction costs associated with CCS is comparatively high for a natural gas plant. In terms of emission permit prices, the break-even estimates are once again quite comparable for the competitive and the regulated power supply scenario. While the operators of natural gas power plants will have weaker incentives to invest in CCS technology, the expected price increases for electricity are nonetheless no more than those for coal plants. Even if CO₂ emission permits were to trade for as much as \$80 per tonne, the adoption of CCS capabilities should limit the rise in the retail price of electricity to about 25%. Those price increases would again be phased in linearly over a period of 30 years if electricity prices are determined according to rate of return regulation and utilities were to receive free emission permits for incumbent plants (100% grandfathering). Less generous emission allowances would accelerate the initial price increases and lead to nonlinear price trajectories over the next 30 years.

The emergence of CCS technology also has implications for comparing coal and gas plants in terms of their cost-effectiveness. The findings in [3] indicate that coal-fired plants will have a lower long-run marginal cost per kWh. This cost advantage, however, is very much dependent on CCS technology being available on the financial terms currently projected in the engineering literature. The cost advantage of coal will be more substantial for either low CO₂ emission charges below \$20 per tonne or for charges sufficiently high, say in the range of \$40-70 per metric ton. In contrast, the two fuel sources are quite comparable in terms of product cost for a mid-level range between \$20-40. It should be noted, however, that in the

absence of CCS technology the cost advantage of coal would reverse quickly once the market price of CO₂ emissions exceeds \$27 per ton. This conclusion again reflects that because of their relatively high emissions traditional pulverized coal plants are far more sensitive to emission charges.

The above estimates have been derived for new power plants to be built in the future. Yet there are also several pilot projects underway seeking to demonstrate the feasibility of retrofitting existing plants with CCS capabilities. While retrofitting an existing plant is likely to add higher incremental construction costs than providing a new plant with CCS capabilities, the retrofit option may nonetheless prove economically important. In a scenario of rapidly rising CO₂ emission charges, retrofitting a plant with CCS capabilities may substantially extend the emission price range for which older power plants, in particular those fueled by coal, remain economically viable. At the same time, a retrofit option would allow the abatement potential of CCS to be realized over a shorter time horizon.

In sum, CCS technologies for fossil fuel plants have considerable promise in terms of their potential to cut CO₂ emissions by very substantial margins relative to the targets commonly envisioned over the next 40 years. Coal-fired power plants, in particular, should be seen as “low-hanging” fruit in terms of their cost-effectiveness. While retail electricity prices are likely to increase gradually to a factor of about 25% above current levels, CCS technology should be seen as an expedient vehicle for providing an effective limit on the market price of CO₂ emission charges that is likely to emerge under a cap-and trade system. These findings reinforce the urgency of fully demonstrating the feasibility of different CCS technologies for plants on a commercial scale. From a public policy perspective, demonstration projects like the FutureGen project in Illinois are therefore of crucial importance.

References

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