

VOLATILE CO₂ PRICES DISCOURAGE CCS INVESTMENT¹

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Abstract

Climate policy proposals based on cap and trade mechanisms with tight caps will likely lead to highly volatile CO₂ prices. This volatility is ignored in many studies, even though it can be expected to exceed that of natural gas and to exceed the wide ranges in CO₂ price forecasts. Volatility will significantly increase investment risk, raise the cost of capital, and make it valuable to defer investments. The net result could be that CO₂ price volatility becomes an impediment to the very investments that the climate policy is attempting to encourage. Compared to a carbon policy regime with more predictable carbon prices, we estimate that CO₂ price volatility under current policy proposal could delay investment in low-carbon and carbon abatement technologies by 10 years or more. We propose that an effective policy to reduce this investment barrier would be a safety-valve mechanism that includes both a floor and a ceiling on CO₂ prices. This would reduce volatility and protect both investors and customers from extreme carbon prices.

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1. INTRODUCTION

Current climate policy proposals in the U.S. mostly involve a cap and trade mechanism with increasingly tight caps on carbon emissions over time. While most economists and many climatologists agree that a market-based approach is necessary to elicit an efficient response to global warming, there are several design and implementation issues that will determine its efficacy. These include the level of the cap, how allowances are auctioned or allocated, and what kinds of offsets are allowed. One aspect that is less often discussed, but may be quite important to climate policy efficacy, is the potential for CO₂ price volatility and how it is managed.

Volatility/uncertainty in CO₂ prices is very likely to be high, assuming the caps are set at levels that significantly reduce CO₂ emissions. High volatility could have detrimental effects on the deployment of long-lived, capital-intensive CO₂ abatement technologies, as well as on the economy in general. Since the proposed reductions in CO₂ emissions are very large (*e.g.*, 50% reductions from current emission levels targeted by 2040 in the 2007 Lieberman-Warner proposal), massive replacement and/or conversion of the existing U.S. generation assets and infrastructure will be needed.

The purpose of this paper is three-fold. *First*, we review the extent of volatility likely to surround long-run CO₂ prices under cap and trade proposals. We believe that likely CO₂ price volatility is understated even by the wide ranges in CO₂ price forecasts, and it is likely to exceed that of natural gas. A standard deviation of 50% or more per year for CO₂ prices is plausible. *Second*, we examine the foreseeable effect of CO₂ price volatility on investors' willingness to undertake long-lived, capital-intensive, and low-CO₂ technologies. We show CO₂ abatement technologies could be deferred many years until CO₂ prices are perhaps double the levels where they would be justified absent the volatility. *Third*, we suggest policy implications and alternatives for mitigating volatility and fostering earlier, safer investment in low-CO₂ technologies. We suggest a safety valve mechanism that includes a slowly evolving price floor to protect investors and a ceiling to protect customers, along with other support mechanisms.

2. VOLATILE CO₂ PRICES LIKELY UNDER CAP-AND-TRADE PROPOSALS

One of the recent widely discussed and widely analyzed climate policy proposals in U.S. is the “America’s Climate Security Act”, introduced by Senators Lieberman and Warner in October 2007. Their proposal, which we will refer to as “L-W,” is a “cap and trade” system that puts increasingly restrictive limits (caps) on the allowed emissions of greenhouse gases (including CO₂) from large facilities in electric, industrial facilities, refineries, and importers of petroleum products and chemicals. These sectors cover about 75% of the total emissions in U.S.² The proposed cap on emissions starts at 5.2 billion tons in 2012 (the 2005 level of emissions for these sectors) and decreases to 4.4 billion tons per year in 2020 and to 1.6 billion tons in 2050 (roughly one-third of the covered industries’ emissions in 2005).

The covered facilities would be allocated some transitional allowances free of charge, with the number of free allowances decreasing from 40% of the cap in 2012 to zero by 2036. The balance would be sold at annual auctions. If a covered facility emits more than its allocated emissions, it would have to purchase allowances in the annual allowance auctions or in the secondary market from other entities. Therefore, L-W results in a CO₂ price set by the market (through auctions and trading) that will have to be paid by the emitters of greenhouse gases. *One important feature of L-W, which is the focus of this paper, is that it does not include any floor or ceiling on CO₂ prices.* As a result, it is likely that CO₂ prices will be highly variable and uncertain, especially in the long-term.³ Volatile CO₂ prices have been observed already in Europe, especially in the Phase I of the Emission Trading System (ETS) that ran from 2005 to 2007. The CO₂ futures prices for 2007 delivery ranged between almost €0 and €30 per ton of CO₂ during just the twelve month period May 2006 – May 2007 in Phase I. So far, Phase II allowance future prices have been relatively more stable, but still have ranged between €15-25/ton during April 2006 – December 2007 for 2009 delivery.

² The 25% of emissions not covered by L-W include small generation plants and industrial facilities, commercial and residential boilers and space heaters.

³ Although the ability to bank and borrow allowances in the L-W can be expected to mitigate the short-term and transient volatility, long-term volatility from persistent shocks to the demand of allowances and to the cost/availability of abatement technologies would not likely be mitigated. See Fell, H., I. MacKenzie, and W. Pizer, “Prices versus Quantities versus Bankable Quantities”, Discussion Paper, Resources for the Future, July 2008.

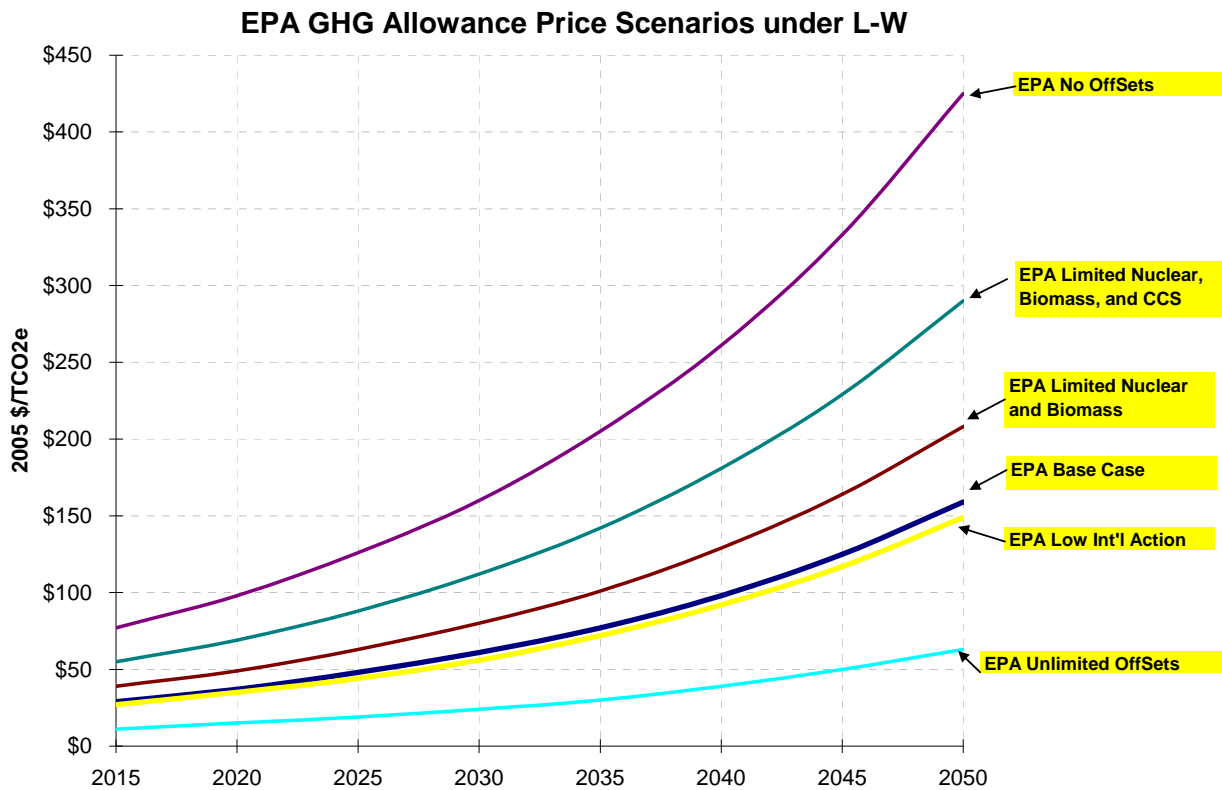
CO₂ prices are intended to reduce the use of CO₂-intensive facilities (*e.g.*, fossil fuel-fired electric generators, refineries, industrial facilities) by making these facilities more expensive to operate. CO₂ prices also are intended to increase the attractiveness of investing in low-CO₂ facilities (such as nuclear and renewable electric generators, coal-fired generators with carbon capture and sequestration (CCS), bio-ethanol, hybrid cars, and the like) by making these facilities more economic. However, CO₂ prices sufficient to materially alter carbon emissions in the electric sector are likely to be high, *i.e.*, \$30-\$70/ton. The middle of this range is enough to raise wholesale electric power prices by more than 50% (though this would occur gradually, over many years). In order to achieve even more reductions in CO₂ emissions (up to 80% reductions discussed in recent climate policy proposals), the required CO₂ prices may have to exceed \$200/ton. A \$100/ton of CO₂ price would affect a meaningful proportion of GDP: five billion CO₂ tons/year at \$100/ton corresponds to \$500 billion/year for the value of CO₂ allowances, or a bit more than 3.5% of 2007 GDP.⁴

Several government agencies (EIA and EPA), research centers (*e.g.*, Nicholas Institute), and other organizations (*e.g.*, Clean Air Task Force and American Council for Capital Formation) have conducted and published studies that estimate possible future CO₂ prices under L-W. As shown in Figure 1 for just the EPA's estimates⁵, these estimates vary significantly -- by factors of two to four, or +/- 100% across analyses -- due to different assumptions, uncertain demand for allowances, changes in energy efficiency, availability/cost of mitigating technologies, alternative policy specifications, and the availability/price of offsets. For example, the price estimates by the EPA for the year 2020 ranges from \$15/ton to \$98/ton, and this range increases to \$24-160 in 2030 and \$63-425 in 2050. These are very wide ranges, and such extreme uncertainty is bound to affect willingness to invest in long-lived, capital-intensive, CO₂-mitigating equipment (whether industrial or individual) that must earn a payback over many years.

⁴ Of course, the majority of CO₂ allowance costs result in wealth transfers, not reductions to GDP. The point here is that these impacts will be very substantial. Actual GDP losses are typically predicted to be less than 1% per year in EIA's analysis of L-W, and between 1-4% per year in EPA's analysis of L-W (for year 2030).

⁵ EPA's CO₂ price estimates for L-W span the range of prices estimated in other studies, with the exception of ACCF/NAM scenarios which estimate higher prices than any other study in years 2025 and 2030.

Figure 1⁶



There are at least three ways in which CO₂ price uncertainty could discourage or delay such investments:

- by increasing the discount rate on NPV analyses; or
- by causing the buyer or builder to wait until the prevailing price for CO₂ is sufficiently high that it is unlikely to drop below the level that would achieve an acceptable payback. (*i.e.*, at some CO₂ price above the level at which the investment would be expected to just break even); or
- by causing the buyer to recognize the option value of waiting for more favorable circumstances.

One of the most well-established tenets of financial economic theory is that the discount rate for determining the present value of future cash flows should be higher for risky investments than

⁶ Environmental Protection Agency, “EPA Analysis of the Lieberman-Warner Climate Security Act of 2008 - S. 2191 in 110th Congress”, March 14, 2008.

for safe ones. Financial risk is measured in a precise sense, referring to both the magnitude of the unpredictable variability in future cash flows, as well as to the tendency of that variability to be correlated with the financial markets and the macro-economy as a whole. To the extent this correlation is present, such risk cannot be diversified away, so it commands a premium in order to attract investors. For reasons discussed later, we expect that the volatility in CO₂ allowances will have a positive correlation with the market as a whole. Empirical analysis of European CO₂ emission rights confirms this expectation.

Many of the carbon abatement technologies with high potential impact are very capital-intensive (CCS, nuclear plants, biofuel refineries, etc.), and they are likely to use significant debt financing. Lenders do not participate in the “upside” payoffs from an investment, so they tend to focus heavily on the “downside” of what could go wrong. Worst-case analyses tend to constrain their willingness to lend. High CO₂ price volatility increases such concerns.

Another insight from financial economics is that the optimal time to invest is not necessarily when an asset first offers a positive net present value (NPV), *i.e.*, appears to have future benefits worth more than expected costs. In some circumstances, it will be optimal to wait a while, in order to let some of the risk about future prices or costs (and the resulting asset value) be resolved. This insight does not require or assume that at some point in the future the risk or uncertainty will collapse and become inconsequential. Rather, it recognizes that over a modest waiting period, the critical prices or costs affecting the value of the asset under consideration could either rise enough that the upside potential to investing will become greater, or fall enough so that the downside becomes obvious and the investment can be avoided.

For this delaying strategy to be economic, it has to be the case that there is some interim alternative to not making the investment immediately. When this interim cost is not too high but the market uncertainty is large, it may be best to “wait and see”. CO₂ allowances themselves provide that interim alternative, since they can be purchased for a while in lieu of making a CO₂ abatement investment. The optimal “time to invest” has been evaluated using option pricing

techniques in papers by Majd and Pindyck⁷, and Pindyck⁸, and others. Here, we apply a simplified decision analysis of the issues addressed in that “real options” literature.

The negative effects of volatility in CO₂ prices on the profitability of low-CO₂ generation power plants, such as nuclear facilities, are also recognized in academic literature. A recent paper by Richard Green found that the volatile CO₂ prices under a cap-and-trade system would result in higher volatility in profits of nuclear generators, leading to a lower proportion of nuclear plants in new generation portfolio, compared to the carbon-fee approach.⁹ The application of option value techniques to evaluating investment in low-CO₂ generation technologies is discussed in a 2007 paper by Yang and Blyth. One of the predictions of that study is higher thresholds for investing in low-CO₂ technologies as a result of higher volatility in carbon prices.¹⁰

3. EXTENT AND CAUSES OF VOLATILITY

We calculated the standard deviation of CO₂ prices from various studies listed above as a rough measure of CO₂ price volatility for each year in the future. It is primarily long-run volatility that we are concerned with, not daily or even monthly variation in prices.¹¹ We are looking for volatility that affects the confidence investors may have in the value of their investments. Projected annual prices from long-term models are an appropriate place to look for such data, much like an investor might use those conditional forecasts in the planning stages of a potential carbon-abatement expenditure. The implied volatility (standard deviation) in L-W annual CO₂ prices in the various studies cited above ranges from \$21/ton in 2020 (or 46% of that year’s mean price estimate of \$45/ton) to \$100/ton in 2050 (49% of the mean estimate of \$205/ton). We should note that this measure of volatility is technically not the volatility around expected CO₂ prices, but the dispersion across conditional estimates of CO₂ prices in various studies. We

⁷ Majd, S. and R.S. Pindyck, “Time to Build, Option Value, and Investment Decisions”, June 1985, Energy Laboratory Working Paper No. MIT-EL 85-011-WP.

⁸ Robert S. Pindyck, “Options, Flexibility, and Investment Decisions”, March 1998, Center for Energy Policy Research, Workshop on New Methods for Project and Contract Evaluation.

⁹ Richard Green, “Carbon Tax or Carbon Permits: The Impact on Generators’ Risks”, *The Energy Journal*, Vol. 29, No. 3, 2008.

¹⁰ Yang, M. and W. Blyth, “Modeling Investment Risks and Uncertainties with Real Options Approach”, International Energy Agency Working Paper Series, February 2007, page 23.

¹¹ Except insofar as short-run volatility is reflected in the discount rate.

assume that the forecast estimates we reviewed correspond to equally likely scenarios spanning most of the probability distribution function of CO₂ prices. This is obviously a simplifying assumption, but the possible resulting errors go both ways: to the extent the results of these studies include low-probability scenarios concentrated on extremes, this calculation will be too high. On the other hand, if these studies have deterministic assumptions omitting major sources of volatility, this calculation of the volatility will be low. In addition, it may be that some early resolution of uncertainty will occur that eliminates exposure to some of the distant future uncertainty. However, that possibility can only be a conjecture at this time.

We believe it is more likely that our simple estimate understates, not overstates, the true uncertainty likely to prevail for future CO₂ prices because the models forecast CO₂ prices arising from assumed deterministic conditions on major drivers of CO₂ prices, such as the price of natural gas or plant construction costs. Many of these factors are themselves highly uncertain, and their stochastic behavior will affect the marginal cost of reducing CO₂ emissions. For example, in the electric sector, CO₂ emissions can be reduced through dispatch-switching from existing coal-fired generation to existing gas-fired combined-cycle plants that emit less CO₂, or through replacing CO₂-intensive generation capacity with new, low-CO₂ generation capacity, among other strategies. Each of these solutions requires CO₂ prices to exceed certain threshold (break-even) levels before they become economic. Those break-even CO₂ prices become higher as gas prices become higher.¹² For example, at a \$7/MMBtu gas price (roughly corresponding to average Henry Hub prices in 2007), CO₂ prices need to be around \$35/ton to cause dispatch switching from the least efficient 50 GWs of coal plants currently operating in the U.S.¹³ This threshold increases to \$82/ton for a \$12/MMBtu gas price. This gas cost is just a bit less than the 2009 forward strip prices as of the beginning of July 2008. Gas forwards as of mid-January 2009 have fallen back to around \$5-8/MMBtu for 2009-2012, illustrating how volatile gas prices can be. Interestingly, volatility in gas prices creates even greater volatility in the break-even CO₂

¹² As coal prices get higher, the required CO₂ price for switching to gas gets lower. However, coal prices are historically much more stable than natural gas prices.

¹³ Based on unpublished analysis by *The Brattle Group* using estimated full-load heat rates and operations and maintenance (O&M) costs of the generation units in U.S. as of 2006. The dispatch switching from a coal unit to gas CCs is assumed to occur when the sum of fuel, variable O&M and CO₂ allowance costs for a coal unit equals such costs for a gas CC at 7000 btu/kWh heat rate. The locations of the generation units are ignored.

prices. In this example, gas prices increased by 71% (from \$7 to \$12), while the resulting break-even CO₂ price increased by 150% (from \$34 to \$82). Thus natural gas prices will likely be a significant contributor to volatility in CO₂ prices as long as dispatch switching in the electricity sector is a major source of CO₂ reductions on the margin -- and gas itself is quite volatile. During the period 1995-2008, the standard deviation of annual average gas prices was about 27% of the average gas price during that period. As of October 2008, the Henry Hub futures strip for all months of 2009 had an annualized volatility of 38%.

Another source of CO₂ volatility will be the uncertainty in construction costs for low-CO₂ technologies. In recent years, significant increases in construction costs have been observed, largely due to demand from China for industrial commodities and equipment. A June 2008 presentation by FERC¹⁴ indicated that the cost range for overnight costs for a conventional coal plant had increased from \$1000-1500/kW range in 2004 to \$1700-4000/kW (more than 100% increase) by early 2008. Similarly, the estimated costs of a nuclear plant had increased from \$1300-2200/kW in 2004 to \$4500-7500/kW in 2008 (up more than 200%). Using cost assumptions typically applied by the utility industry in early 2007, the levelized costs of an Integrated Gasification Combined Cycle (IGCC) with a CCS plant would have been economic relative to an IGCC plant without CCS at a CO₂ price exceeding \$40/ton. The break-even CO₂ price for IGCC with CCS against conventional supercritical (SC) pulverized coal plant was higher, at about \$48/ton, while nuclear became economic relative to SC coal at CO₂ prices exceeding \$55/ton. However, if the construction costs of these plants all increase by 50%, these break-even CO₂ prices increase substantially to \$53/ton (a 33% increase), \$65/ton, and \$88/ton, respectively. Thus, volatility in plant construction costs will likely be another significant source of volatility in CO₂ prices. This factor, like gas price uncertainty, was not considered explicitly in the scenario modeling by EPA, EIA, *et. al.*, from which we derived our CO₂ volatility estimate.

¹⁴ FERC, "Increasing Costs in Electric Markets", June 19, 2008, page 11, posted at <http://www.ferc.gov/legal/staff-reports/06-19-08-cost-electric.pdf>. Like fuel costs, construction costs may have recently fallen due to the credit crisis and resulting recession.

CONCLUSIONS ON LIKELY CO₂ PRICE VOLATILITY

CO₂ price volatility under a cap-and-trade policy with features similar to Lieberman-Warner proposal is likely to be:

- 1) Around 50%, as implied by price projection studies;
- 2) Greater than it appears from projection ranges, due to additional sources of volatility not considered in those studies;
- 3) Greater than fossil fuel price volatility, especially natural gas (which in mid-2008 had annual volatility of around 30-40%).

4. IMPACT OF VOLATILE CO₂ PRICES ON CCS INVESTMENT

In order to isolate the effect of CO₂ price volatility on CCS investment, this report addresses the incremental costs and benefits of CCS relative to an IGCC plant without CCS. Although IGCC with CCS is a technology that is still under development and has not been deployed yet, the cost of building an IGCC plant with and without CCS have been estimated in several studies. We assume that the costs and performance characteristics will be close to those implied by the recent FERC estimates, recognizing the significant rise in construction costs in the last few years. Specifically, we assume that CCS adds about \$1000/kW (33%) to the construction cost of an IGCC, increases the heat rate by about 20%, and increases the fixed O&M costs by \$10/kW-year and variable O&M by \$2/MWh approximately. We also assume it extracts 90% of the CO₂, which can be transported and stored for \$5/ton. The appendix to this report presents a summary of the assumptions for key parameters (overnight costs, heat rates, and CO₂ emission rates) we adopted for our analysis.

Using these assumptions, we estimated the present value of the revenue requirements per installed capacity (in \$/MW) of each technology excluding CO₂ allowance costs. CCS adds about \$2.5 million per MW (about 30%), or \$2.5 billion for a 1000 MW plant, to the present value revenue requirements of an IGCC plant (\$7.7 billion) over 30 years. About 65% of this is due to higher construction costs for the carbon capture at the IGCC, with the balance due to cost of building and maintaining the CO₂ pipelines and sequestration, higher variable costs from using about 10% more fuel to power the CCS process, and about 10% higher O&M costs.

An investor must have reasonable confidence that this present value CCS cost of \$2.5 billion can be recouped via avoided CO₂ prices before making the CCS investment. Given the above assumptions, and ignoring the impact of uncertainty, CO₂ prices need to be at least \$30-35/ton in order to outweigh this CCS cost disadvantage.¹⁵ In the following section, we demonstrate three ways in which risk aversion associated with CO₂ price volatility might be manifest, and might make the break-even CO₂ price for willingness to develop CCS much higher.

a. MECHANISM 1: HIGHER DISCOUNT RATE FOR AVOIDED CO₂ COSTS

In evaluating future streams of revenues from any commodity or financial instrument, one key step is to determine the discount rate that reflects the riskiness of that commodity or instrument relative to the rest of the economy (*i.e.*, systematic risk). The riskier the future revenues from an asset or commodity, the higher the discount rate, hence the lower the present value of the revenues (conversely, the higher the required break-even price).

Under any cap and trade program with a stringent and tightening cap, it is reasonable to expect that CO₂ prices will have some systematic risk, as a result of the links between the CO₂ prices and macroeconomic factors. The demand for CO₂ allowances will be partly determined by the level of economic growth, and to some extent, the price of allowances may be even set by the value of goods foregone in order to meet the cap. In periods when economic activity increases, demand and prices for CO₂ allowances probably both will increase. A reliable estimate for the expected discount rate risk premium for CO₂ prices is difficult to develop at this time, due to lack of historical data for a similar CO₂ allowance market applied elsewhere. However, review of the historical CO₂ prices in the European Union Emission Trading Scheme (ETS) provides a useful

¹⁵ The analysis in this paper ignores the CCS bonus allowance mechanism in L-W. This mechanism sets aside a certain number of CO₂ allowances issued over time to be allocated freely to generation plants using CCS. These free CO₂ allowances will reduce the total cost of CCS for early adopters of the technology (assuming a CO₂ price greater than zero), but they should not affect our conclusion on the detrimental effects of inherent price volatility on CCS investment, for two reasons. First, since the value of bonus allowances is directly a function of CO₂ prices, the bonus itself will be uncertain due to the volatility in CO₂ prices. Second, the hard cap on total CCS bonus allowances in the L-W likely limits the deployment of CCS. Compared to a soft cap on total CCS bonuses as in the Bingaman-Specter proposal, the hard cap in the L-W could result in 50% less coal and gas generation plant capacity using CCS.

benchmark, as discussed in the box below. This market experience indicates we can expect a beta of about 0.65 and a resulting risk premium¹⁶ of about 3.0% (over short-term government bills). This is likely to be a lower bound estimate for the risk premium under L-W, since systematic risk will likely be higher under L-W (with its much tighter (lower) emission caps) than under the caps implemented in the ETS program so far. The total annual caps approved by EU for 21 countries for the period 2008-2012 amounted to about 1.86 billion tons, just slightly below the actual emissions of 1.91 billion tons in 2005.¹⁷

BETA AND RISK PREMIUM FOR CO₂ PRICES

Using the Euro zone futures data on CO₂ emission allowances (EU Allowances, or EUA) from the European Climate Exchange (ECX) website we regressed monthly futures returns on the corresponding market risk premiums.

The CO₂ futures returns were constructed by annualizing the natural logarithm of price ratios for monthly multi-month futures prices. The latter are constructed by adding together futures prices (discounted to the quote date at the 12-month Euribor rate) for contracts expiring more than 12 months, but less than 48 months, after the quote date. The data spanned the period from April 2005 to May 2008, resulting in 38 observations of monthly returns.

Using Euribor rates as the risk-free rate, and FTSE Eurofirst 100 index as the market return index, we estimated the beta coefficient to be 0.64. The standard errors of the estimate indicate close to 10% level of significance, and the R-square of the regression of about 7%, a level typical of beta estimation studies generally. Given an estimated long-term market risk premium of 4.5% over bills for the European countries, we obtain a risk premium on CO₂ futures returns of about 3% per year.

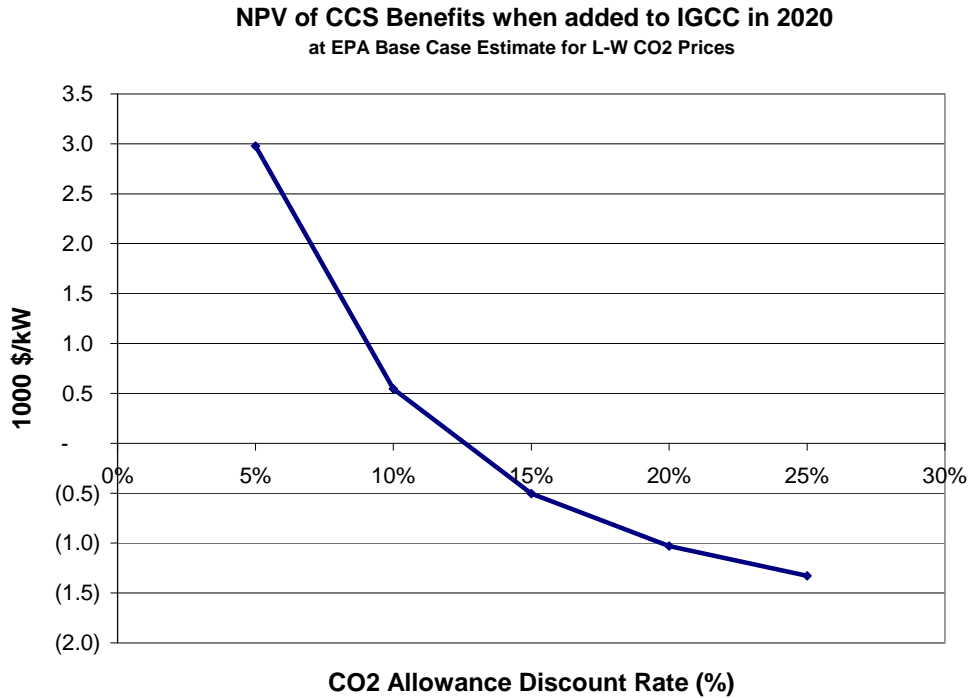
Figure 2 shows the Net Present Value (NPV) per MW for CCS investment as of 2020 under the EPA's base case estimate of the expected real CO₂ price trajectory (about \$40/ton in 2020, \$100/ton in 2040) at different levels of discount rate (real ATWACC). The NPV of the CCS

¹⁶ The market risk premium for European countries are obtained from Dimson, E., P. Marsh, and M. Staunton, "Global Investment Returns Yearbook 2007", London Business School, February 2007, Table 10.

¹⁷ EU press release posted on May 15, 2007 at <http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/667&format=HTML&aged=0%3Cuage=EN&guiLanguage=en>. See also a recent paper by Lesley McAllister for a discussion of the evidence that the EU caps were set too low ("The Overallocation Problem in Cap and Trade: Moving Toward Stringency", University of San Diego School of Law, Legal Studies Research Paper Series, Research Paper No. 08-076, October 2008, pages 8-9.).

investment is positive at discount rates lower than 15%. Above this rate, CCS on an IGCC plant is not economic, absent higher expected CO₂ prices.

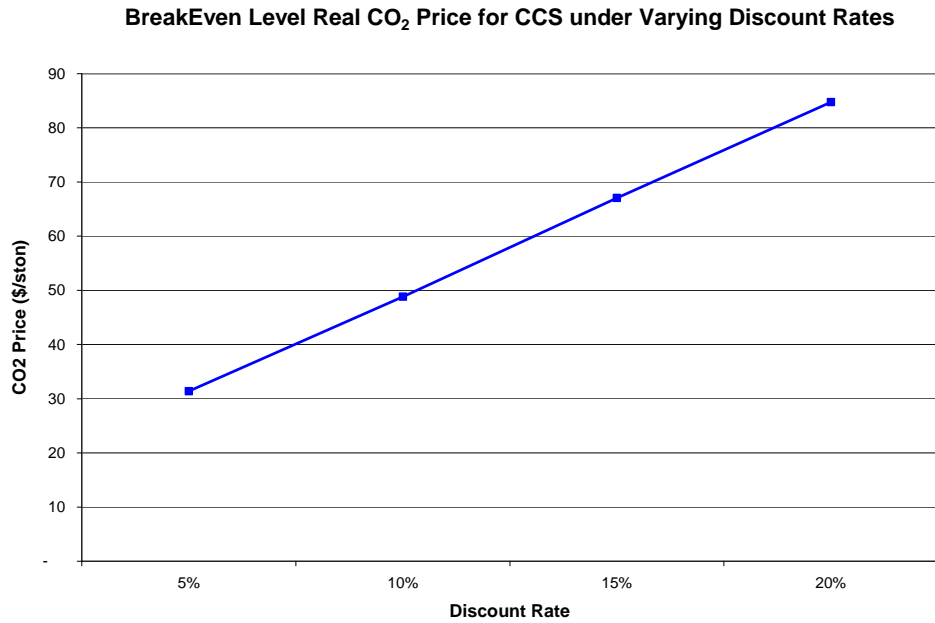
Figure 2



Equivalently, we can calculate the minimum expected level real CO₂ price at which CCS becomes economic as a function of the discount rate. We show in Figure 3 that the break-even CO₂ price increases as the discount rate (real ATWACC) for CO₂ prices increases. At a 5% real discount rate, roughly corresponding to cost of capital for a low-risk utility company, the levelized real price of CO₂ needs to be around \$31/ton to make CCS economic.¹⁸ At a 15% discount rate, the break-even CO₂ price increases to \$66/ton, more than double the required low-risk CO₂ price.

¹⁸ This level of CCS break-even, at \$31/ton, is a bit below most estimates because it assumes a very low cost of capital. For clarity, it is worth emphasizing that CO₂ revenues (or avoided costs) are applied against just the CCS. The IGCC is itself assumed to be economic already. If the IGCC must also use CO₂ prices to cover its own cost disadvantage against conventional resources, then higher CO₂ prices would be needed. However, \$31/ton would still be the *incremental* CO₂ price needed to justify the CCS.

Figure 3



If public policy could be designed to reduce CO₂ price risk, *e.g.*, through lowering the variance in potential CO₂ prices and/or lowering their correlation with the macro economy, the CCS technology would be economic at lower CO₂ prices. One way to do this is to introduce a price ceiling and floor so that extreme variations in prices are dampened. Such policy levers for managing CO₂ volatility are discussed in the last section of the report.

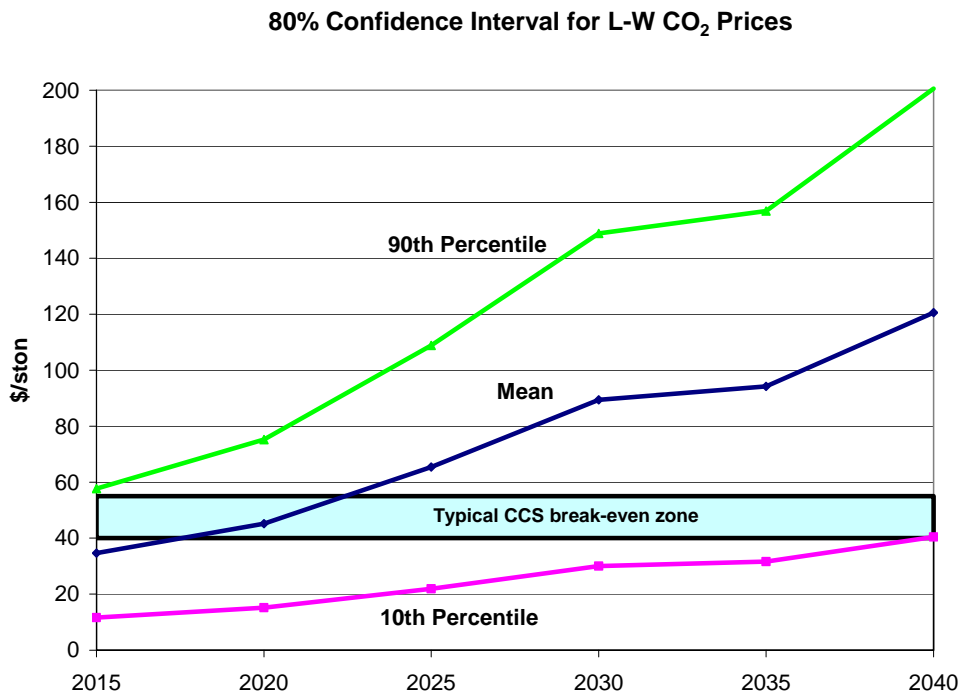
b. MECHANISM 2: HIGHER REQUIRED CO₂ PRICE DUE TO MANAGERIAL AND INVESTOR RISK AVERSION AGAINST WORST-CASE INVESTMENT SITUATION

Instead of increasing their hurdle rates in anticipation of CO₂ volatility, investors may deal with this risk through the use of deliberately conservative price estimates in their analysis of a carbon abatement investment like CCS. For example, some investors may apply a “worst case” standard by testing investment against a price for CO₂ at the 10th percentile of its distribution (that is, provides a 90% expectation of achieving or exceeding break-even), instead of its expected value. The greater the expected volatility, the lower the worst-case price in such a test. Even if equity investors do not apply a worst-case test, it is very likely that lenders will. They typically use a worst-case scenario before extending debt for project financing, so this risk-adjustment

methodology reflects the feasibility of obtaining funds, even if the equity investors are not so risk-averse.

An illustration of the consequences of this conservative approach is seen in Figure 4. As discussed earlier, we have estimated a lower bound on the standard deviation of annual CO₂ prices under L-W to be equal to 50%. Assuming a normal distribution, CO₂ prices will be within $\pm 65\%$ (1.3 times the standard deviation) of the mean with 80% probability.¹⁹ Applying these estimates to average of the L-W CO₂ price estimates from various studies discussed earlier, the following figure shows the estimated 10th to 90th percentile range over time. A horizontal band is drawn on this graph at the \$40-55/ton range of CO₂ prices often cited as necessary for CCS break-even. Note that this level is achieved almost immediately by the average price curve, but not reached by the 10th percentile curve until 2040 -- more than a 20-year delay! By then, expected prices could be above \$100/ton.

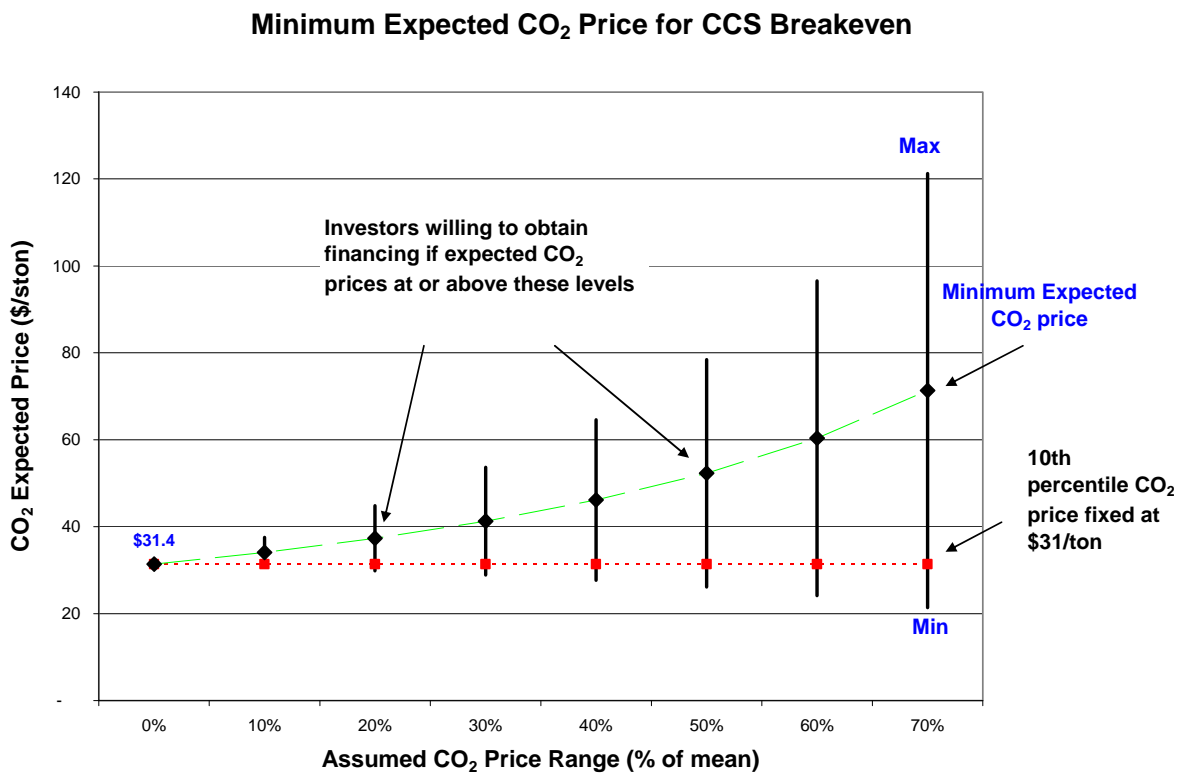
Figure 4



¹⁹ It is possible, perhaps even likely, that CO₂ prices will actually be lognormally distributed, as is typical of many commodities. However, a normal distribution suffices to illustrate our concerns about volatility.

As previously demonstrated, if there were no volatility in CO₂ prices, then the average, level real CO₂ price necessary to justify CCS investment would be the \$31/ton shown previously under a 5%, low-risk discount rate. Of course, investors and lenders realize that CO₂ prices could fall below \$31/ton with some positive probability, so in order to pass a conservative, worst-case investment test, the expected value of CO₂ prices must rise. The vertical bars in Figure 5 show how the expected level price threshold rises as CO₂ price range increases. For example, if an investor wants CCS to break-even at the 10th percentile on CO₂ prices with ±70% range around expected value, then the expected level real CO₂ price must be at least \$71/ton. Again, this means the risk-averse lender or investor may wait for years for prices to rise above no-risk break-even levels before proceeding with CCS investment.

Figure 5

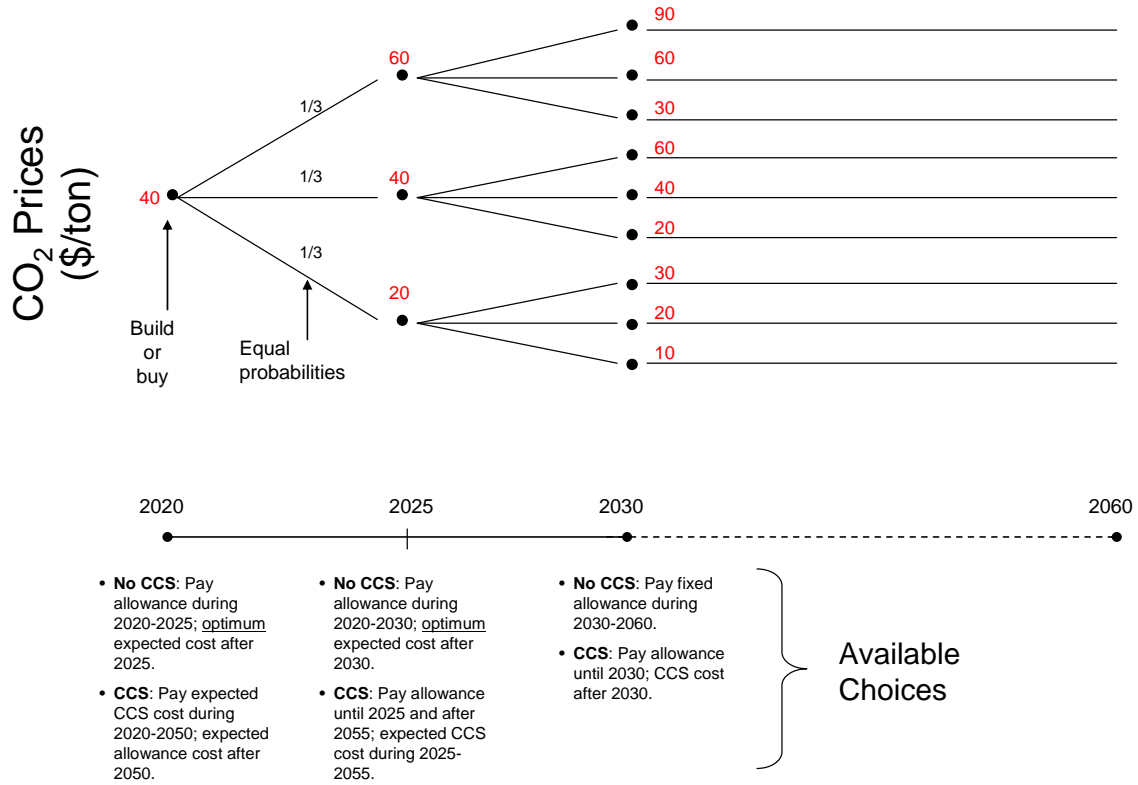


c. MECHANISM 3: VOLATILE CO₂ PRICES INCREASE THE OPTION VALUE OF WAITING

The irreversible nature of generation investments, especially the baseload, low-CO₂ technologies with large capital costs such as IGCC with CCS or nuclear generation, requires a prudent investor to consider the value of waiting for auspicious conditions to invest in these generation plants. A given investment typically has a range of mutually exclusive alternative installation dates, so an investor should invest when the net present value of investment is both positive and the current timing is best, *i.e.*, value is maximized. This may well be several years after the investment first begins to have a positive NPV. In the case of long-lived, capital-intensive investments like CCS investment, the option value of waiting will be high if the volatility of the future stream of revenues (here, the avoided costs of CO₂ allowances) is high and if the interim cost of waiting (and paying for near-term CO₂ allowances) is low. We will illustrate the option value of waiting for CCS investment using a simplified, decision-analytic framework rather than full option-pricing techniques. The differences in analytic technique would be important to specific investment decisions, but are unimportant here, due to imprecision in the demonstrative parameters.

Consider a generation plant owner who has already built (or decided to build) an IGCC coal plant without CCS, and who is assessing whether and when to add CCS on that plant to avoid most (90%) of the future CO₂ allowance costs otherwise required for using the IGCC plant. Assume that the economic life of the CCS component is 30 years. Imagine that the plant owner faces just three decision points at 5-year intervals starting in 2020. In 2020 or 2025, the plant owner can either build a CCS (assuming it was not already built five years ago) or wait five more years. If the decision is to wait, the plant owner pays CO₂ allowance costs to cover emissions from its IGCC coal plant for the next five years. If the decision is to build CCS, the plant owner avoids 90% of future CO₂ allowance costs for the next 30 years. To simplify the analysis, year 2030 is assumed to be the last chance to build this particular CCS plant. If the plant owner decides not to build CCS in 2030, then it incurs CO₂ allowance costs associated with its IGCC plant for the entire 30 years until 2060. Otherwise, the plant owner builds the CCS and avoids 90% of the CO₂ allowance costs until 2060. These choices are depicted below in Figure 6.

Figure 6
CO₂ Prices and Decision Points Under a High Volatility Case
(±50% Growth Every 5 Years)

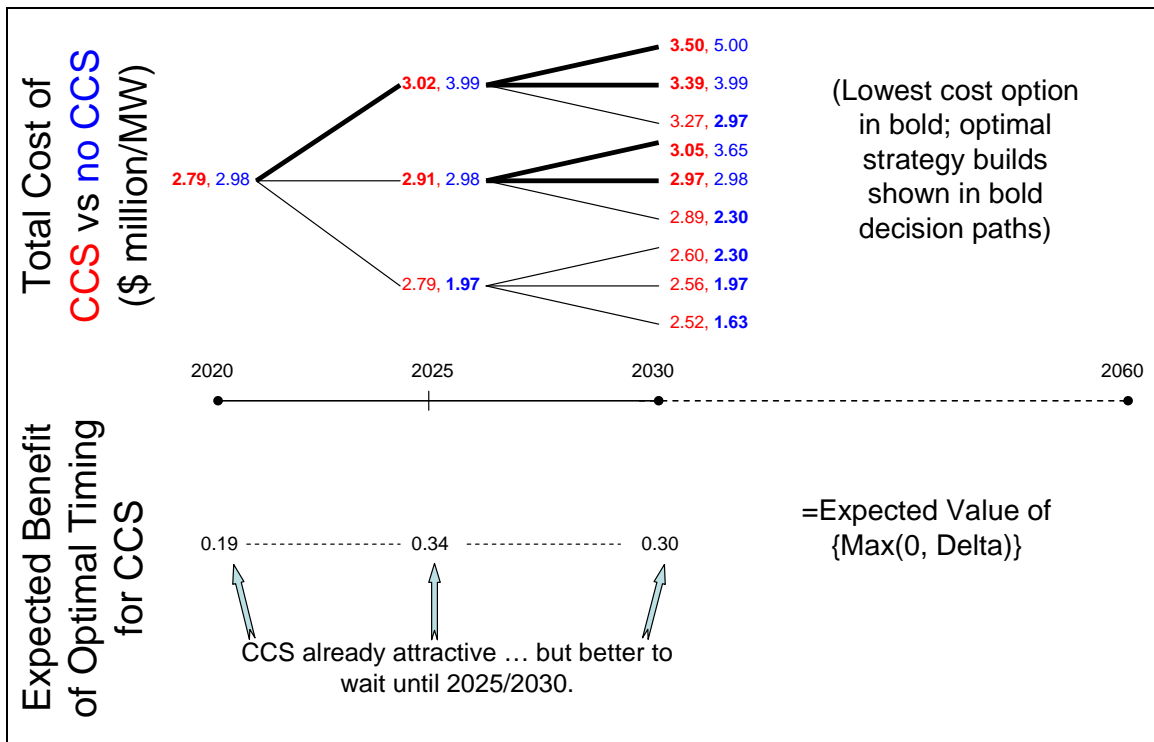


CO₂ prices are assumed to follow discrete price trajectories shown above on the branches of a trinomial tree over time. At each possible CO₂ pricing point, the price is fixed for the next five years (or for the next 30 years in the case of year 2030). In 2025 and 2030, the CO₂ price can take high, medium, or low values (relative to the price in the prior period). The CO₂ prices in the figure above correspond to a case in which CO₂ prices start at \$40/ton in 2020 (roughly equal to the EPA’s base case estimate in 2020 for price of allowances under L-W) and then they either change in 5 years by ±50%, or remain the same, each with equal probability. Hence, the CO₂ price in 2025 will be either high (\$60/ton), medium (\$40/ton), or low (\$20/ton). CO₂ prices branch again in 2030 in the same proportions with equal probabilities and are in the range of \$10/ton to \$90/ton. The *ex ante* annual average remains \$40/ton over time.

As in the previous section, the present value cost of a CCS plant is \$2.5 million per MW. By comparing this against the present value of avoided CO₂ allowance costs under the prevailing range of uncertain CO₂ prices at each decision point over time, as summarized in the diagram above, we can solve for the optimal choice (between building CCS vs. no CCS) at each choice point between 2020 and 2030.

Ignoring the impact of volatility on option value of waiting, the \$40 price in 2020 would barely justify investing in CCS, with a PV advantage in 2020 of \$0.19 million per MW below the costs of not building, evaluated at a 7.5% real discount rate. (This is the difference between expected costs of \$2.79 million per MW for CCS vs. \$2.98 million per MW for no CCS, as shown at the 2020 decision point in Figure 7.)

Figure 7
Optimal Timing for CCS Investment Under a High Volatility Case
(±50% Growth Every 5 Years)



However, accounting for the option value of waiting under 50% volatility in CO₂ prices, waiting optimally further reduces the expected cost. As of 2020, looking ahead five years to 2025 shows that it will not be profitable to build a CCS if the CO₂ price is then \$20/ton in the bottom branch, but it is attractive in the top two branches with CO₂ prices at \$40/ton or \$60/ton. As a result, the expected benefit of paying allowance costs for five years and then building CCS in 2025 (if circumstances are then attractive) yields a PV cost of \$2.64 million per MW, or \$0.34 million per MW less than the no-CCS option. This is a bigger savings than building in 2020, so it is worthwhile to wait. (See Figure 8 below for the gross costs of the alternative schedules and the net advantage to waiting.)

However, the same problem of whether to wait arises in 2025 as well. For example, in the middle range of prices (at \$40/ton), it could turn out that a CCS built in 2025 will not be attractive in one outcome in 2030, if CO₂ prices drops to \$20/ton. So it is optimal to wait again if the price in 2025 is \$40/ton or less (but to build if it is high). This saves an additional \$0.05 million per MW, as shown in Figure 8 below, and it exceeds the benefit of \$0.19 million per MW for building CCS in 2020 by \$0.20 million per MW. This \$0.20 million per MW option value of waiting arises because: i) the interim cost of waiting is not too high (*i.e.*, the \$40/ton CO₂ price is quite close to the break-even price of \$37 at 7.5% discount rate); and ii) the bad outcome of investing in 2020 and discovering prices are low in 2025 and thereafter can be partially avoided. (Prices could still drop to low levels in 2030, but that possibility has a lower probability among the possible outcomes, as seen from the perspective of 2020 information.)

If instead the investor waits for five additional years until 2030, then the expected benefit of optimally building CCS becomes \$0.30 million per MW relative to no CCS alternative. This benefit of waiting ten years and then building CCS still exceeds that of committing to building CCS in 2020, but is less attractive than building CCS, or waiting again, optimally in 2025. Therefore, the optimal delay in CCS investment in this high-volatility case is at least five years, even though the net present value of CCS is already positive as early as 2020.

Figure 8

Summary of Impacts of CO₂ Price Volatility on Break-Even Price and Time to Build

CO ₂ Real Discount Rate		7.5%	7.5%	7.5%	7.5%
Expected CO ₂ Price (\$/ton)		40	40	40	40
CO ₂ 5-Year Volatility (linear growth)		50%	50%	10%	10%
CO ₂ Prices in 2025 \$/ton		20 - 60		36 - 44	
CO ₂ Prices in 2030 \$/ton		10 - 90		32 - 48	
(\$ million per MW)		Gross PV Cost	NPV Advantage	Gross PV Cost	NPV Advantage
no CCS ever	a	2.98		2.98	
CCS in 2020	b	2.79	-0.19 (b-a)	2.79	-0.19 (b-a)
no CCS in 2020, optimal later	c	2.59	-0.20 (c-b)	2.87	+0.08 (c-b)
no CCS in 2025, optimal later	d	2.68	-0.11 (d-b)	2.92	+0.13 (d-b)

advantage to waiting

disadvantage to waiting

Now consider a low volatility case, in which prices can only change by $\pm 10\%$ growth rate in each 5-year period, or can remain the same. Starting with the same CO₂ price in 2020 as in the high volatility case (\$40/ton), CO₂ prices will be in the narrower range of \$36-44/ton in 2025 (in contrast to \$20-60/ton range in the high volatility case), and in the range of \$32-48/ton in 2030 and beyond (in contrast to \$10-90/ton range in the high volatility case). Again, the expected price in all future years, as seen in 2020, is \$40/ton.

With low volatility, the expected benefit of optimally building CCS is again positive in each year, but now the highest benefit is obtained if the CCS is built right away in 2020, without waiting. The expected benefit of paying allowance costs for five years and then building CCS in 2025 only when it is optimal to do so would now be \$0.11 million per MW relative to the no-CCS alternative. This is less than the \$0.20 million per MW expected benefit of building CCS in 2020 without waiting. Similarly, it is more costly to wait for ten years and build CCS optimally in 2030 relative to building it in 2020. Decreasing the volatility in CO₂ prices from 50% to 10% reduces the option value of waiting such that it is now optimal to build in 2020. Lower volatility avoids delaying the CCS investment by five years.

Another way to see the impact of CO₂ price volatility on CCS investment is to assess the impact of higher volatility on the break-even CO₂ price needed to justify not delaying the investment. For different levels of assumed volatility in CO₂ prices, we calculated the expected benefit of optimally building CCS in each of years 2020, 2025, and 2030. As volatility increases, higher expected CO₂ prices are needed to justify not delaying investment. Figure 9 below shows the minimum CO₂ prices needed to avoid delaying CCS investment under varying assumptions on CO₂ price volatility, and assuming a 7.5% ATWACC as discount rate. If the five-year volatility in CO₂ prices is zero (*i.e.*, deterministic CO₂ prices), then a \$37/ton expected CO₂ price is high enough to avoid delaying investment. However, if the five-year volatility increases to 50% (resulting in a range of \$11-103/ton for CO₂ prices in 2030 – a smaller range than the projected range of CO₂ prices under L-W in 2030), investors would need an expected CO₂ price of around \$46/ton to avoid delaying CCS investment. A \$9/ton increase in CO₂ prices corresponds to roughly \$60 billion in national CO₂ costs at current levels of CO₂ emissions in U.S.

Figure 9: Break-Even, No-Delay CO₂ Prices Under Option Value Method

BREAKEVEN CO2 PRICES UNDER OPTION VALUE METHOD (\$/ton)			
5-Year Volatility	CO2 Price Range (\$/ton) in		Breakeven CO2 Price for CCS (\$/ton)
	2025	2030	
0%	37 - 37	37 - 37	37
10%	34 - 42	31 - 46	38
20%	32 - 47	25 - 57	40
30%	29 - 54	20 - 70	41
40%	26 - 61	16 - 85	43
50%	23 - 68	11 - 103	46

d. SUMMARY OF UNCERTAINTY IMPACTS ON CO₂ ABATEMENT INVESTMENTS

While the above examples are simplified, they show the plausibility of CCS not being economically attractive, in light of likely CO₂ price volatility under L-W, until CO₂ prices reach \$65-70/ton, rather than the conventionally estimated break-even levels around \$35-45/ton found in analyses that ignore the effect of volatility. This could cause a delay of perhaps ten years or more in CCS adoption. Other capital-intensive carbon abatement would be similarly affected.

Uncertainty Adjustment	Required CO₂ price	Years of Delay
Higher Discount Rate		
• Low-risk utility (5%)	\$31/ton	0
• Merchant (15%)	\$66/ton	15 years
Worst-Case Scenario		
• 0% σ	\$31/ton	0
• 70% σ	\$71/ton	15 years
Optimal Waiting		
• 10% σ	\$38/ton	0
• 50% σ	\$46/ton	5 or more years

5. SUGGESTED POLICIES TO MITIGATE CO₂ PRICE VOLATILITY

The most direct way to mitigate CO₂ price volatility would be to avoid it, by using a carbon fee approach. Many economists think this would be the best approach, and contrary to much public discussion, would still involve competitive market forces.²⁰ It is not like a command-and-control approach in which specific technologies are imposed. Rather, producers and consumers would choose where and how to cut back emissions using any technologies that cost no more than the fee. It would also be possible to buy and sell offsets that would be used as credits against some portion of fees. Mechanisms to facilitate the transition to carbon pricing could include either ramping up the fee slowly or extending gradually expiring tax credits or exemptions to vulnerable industries. Of course, there is a risk of carbon fees being somewhat uncertain due to lack of political instability in how they are administered, but this risk exists for any CO₂ control policy. Notwithstanding the potential advantages of a carbon-fee approach, a cap and trade framework appears much more likely to be adopted. There is no doubt that a significant amount of CO₂ price uncertainty under cap and trade is simply inevitable, but some of the uncertainty is amenable to policy-based mitigation, to which we now turn.

Presuming legal and regulatory rules for proceeding with large-scale carbon abatement technologies are in place and technological uncertainties are resolved,²¹ then an obvious risk-mitigating lever available to policy makers would be to use safety valves to limit the range on realized CO₂ prices. There is already political recognition that a ceiling should be set, to avoid having the price go too high in the event that we have great difficulty achieving the CO₂ caps. This is important for consumers, but it is not the main problem that investors in CO₂ abatement

²⁰ See *The Brattle Group* discussion paper “The Economics of U.S. Climate Policy: Impact on the Electric Industry” (March 2007) for a discussion of the impacts and advantages of a carbon-fee approach.

²¹ Technological uncertainty can be reduced by aggressive spending by the federal government, and perhaps by state governments or utilities as well, to establish technical prototypes for key control technologies, especially CCS. There is a pronounced public goods aspect to some of the emerging carbon control technologies, as well as significant potential liability from their performance failures, should that happen. The government is the right institution to invest the seed capital to prove the technologies, by funding research and development at a commercial scale for several designs in parallel and publishing the findings on what is most and least effective, and why. Closely related, the government can limit the liability from technical failure, perhaps as it has in the nuclear industry, either by owning and operating, or by indemnifying and insuring, carbon transport and storage facilities. This also may be necessary because of the need for the carbon storage facilities to perform for a thousand or more years. Before these R&D and legal risks are resolved, the market risk associated with volatile CO₂ prices is likely to be a secondary concern.

technologies will be worried about. Investors' main fear is a price collapse.²² Accordingly, CO₂ price floors may be helpful to investors and the associated proliferation of CO₂ reducing technologies. A ceiling is achieved by the government selling allowances at a stated price, if needed to satisfy a tight cap. A floor could be achieved by the government buying back allowances if the price collapsed below some level that was deemed necessary, on average, to attract the next wave of mitigating technology and to provide some degree of revenue stability for recent deployments of long-lived, low-CO₂ technologies. Equivalently, the cap could be tightened, thereby reducing carbon intensity a little faster, if/when it is proving cheaper to do so than had been expected.

Of course, a floor should not apply if a comprehensive, low-cost solution happens to be developed. To avoid this, a floor cannot be fixed in advance and left in place regardless of market circumstances. Rather, it should adjust slowly and circumstantially. For instance, the government could put in a price support at a blend of the recent historical costs and the estimated long run marginal cost of the next, large-scale available means of CO₂ abatement. The contribution of historical costs provides some revenue stability for the existing investments, while the inclusion of long-run cost estimates provides means to update the floor to reflect technological conditions. Alternatively, direct subsidies or tax breaks could be extended to critical technologies (like CCS), thereby lowering the break-even CO₂ price for the private developers.

The key purpose of these price supports would be to eliminate short-term drops in CO₂ prices (of a year or more) that could undermine investors, if and when the long-run problem still seems in need of more costly solutions. For instance, short-term prices might drop artificially if there were:

- Too many free, transitional allowances;
- Too low a cap, or too large a cap reduction if prices were being deemed too high;
- Too many offsets.

²² Another benefit of stable CO₂ prices would be that any government revenues collected from auctions or safety valve sales of CO₂ emission rights would also become fairly stable. This would make climate policy research and development programs or subsidies, and revenue transfer programs to keep the program close to revenue neutral, much easier to administer from year-to-year.

Based on European experience to date, several of these kinds of problems are very plausible.

A third policy initiative that would reduce both the levels and volatility for CO₂ prices would be to introduce some non-price policies in parallel with the cap and trade program. Forecasts that show CO₂ prices becoming extremely high (*e.g.*, hundreds of dollars per ton) often have this result because prices are the sole motivator for CO₂ abatement. In many commodity markets, higher average prices are also associated with higher price variability, and CO₂ prices may behave this way as well. Unfortunately, there are certain activities that are carbon-intensive but not very carbon-cost sensitive. For example, a CO₂ price of \$1/ton raises the price of gasoline by only about 1 cent per gallon. This means that even a \$50/ton CO₂ price would only increase gasoline prices by half as much as they rose from March to July 2008, or from February to May 2007. (A \$10/barrel of increased crude oil prices typically translates into about \$.25/gallon higher prices for gasoline). Thus, CAFÉ standards would be more likely to induce a major, early drop in transportation CO₂ emissions than CO₂ prices. Building and appliance standards may also be cost effective and fruitful. The adjustments these standards require could be funded, in part, by the revenues likely to come from auctioning off CO₂ allowances (or selling them at the safety valve ceiling). By taking some of the burden off of CO₂ prices, it will not be necessary for the entire economy to bear marginal costs to which only a few sectors are directly able to respond.

Some of these policies might reduce the systematic risk associated with CO₂. In particular, safety valve ceilings and floors will tend to dampen some of the connection between the current state of the economy and the price of CO₂. Reductions in CO₂ price uncertainty will benefit not just industrial investors, but also retail “investors” who could make capital improvements in their houses and cars to reduce their own CO₂ footprints. Having greater certainty of payback will encourage those expenditures – and they could be further encouraged through direct subsidies or incentives (such as tax rebates).

It could be argued that the detrimental effect of volatility in CO₂ prices on investment in low-CO₂ technologies should be self-correcting, because reduced investment (delayed by risk) will subsequently increase the unsatisfied demand for allowances and raise CO₂ prices. This is

conceptually correct, provided it is actually allowed to occur, but that may not be the case. First, the link between lack of investment and increased CO₂ prices could be weakened by regulators who may find it politically undesirable to let CO₂ prices reach extremely high levels. Second, if prices climb to a predetermined penalty price for noncompliance, that mechanism will effectively reduce the cap, so that the same amount of total emissions will not be controlled. Third, if the scientific community concludes that there is an ecological upper bound on tolerable cumulative global CO₂ emissions by, *e.g.*, 2050 that must be met regardless of investor preferences and risk-aversion, then any delays in early control will have to be overcome with tighter caps on later control (and again, this may be politically untenable, if CO₂ costs are already high).²³ We will need to regulate the price and quantity of abatement technology development to reach those targets.

This need is similar to the need for capacity markets in some wholesale electric markets in U.S., which are used to ensure resource adequacy by providing some degree of revenue stability and fixed cost recovery assurance for resources. For example, in the PJM RTO region, the required reliability reserve margin (about 15% of peak load) is induced by capacity prices tied to the cost of a new entry capacity. This approach is taken even though the energy market itself would be expected to eventually equilibrate at higher energy prices sufficient to attract entry -- if those results were politically acceptable. To date, such high and volatile energy prices (probably with lower reserve margins as well) have not been considered acceptable, so capacity pricing mechanism have been introduced. CO₂ prices may need similar indirect management.

It is commonplace when considering government regulation of a problem to argue that the government “should not pick winners”. We generally agree with that caution, and we are not advocating as such here. However, it is important to appreciate the huge amount of investment and the potential urgency to invest that global warming presents. While CO₂-reducing technologies are being delayed, CO₂-intensive technologies with long lives are being installed, increasing emissions and creating a greater burden to solve the problem in the future with much tighter caps. Policies that mitigate risks for early adoption of low-CO₂ technologies dampen the

²³ It is also possible that very high CO₂ prices will induce more attempts to satisfy the caps with questionable offsets.

need for rapid escalation of CO₂ prices in the future, hence allowing the production and consumption patterns to adapt smoothly to rising CO₂ prices. The inefficiencies from trying to pick winners may be more than offset by the lost time and higher CO₂ emissions from waiting for the market to sort out the best technologies. Indeed, the market may not be willing to pick any players at all, no less identify the winners, unless there is government clarity about the program and its operations over decades. Furthermore, we are likely to need every kind of approach that has a half-decent prospect of succeeding, as no single technology, sector, or country can solve this problem. Thus, the elegance that might normally be sought from a pure market solution may be a luxury we cannot afford.

6. CONCLUSIONS

We find that the extent of volatility likely to surround long-run CO₂ prices under cap and trade proposals is probably understated even by the wide ranges in CO₂ price forecasts. A standard deviation of 50% or more per year for CO₂ prices is plausible, even after policy rules are finalized, unless those policies explicitly address price volatility. High CO₂ price volatility will deter investors' willingness to undertake long-lived, capital-intensive, low-CO₂ technologies. CO₂ abatement technologies could be deferred many years due to price volatility, until CO₂ prices are perhaps double the levels where those investments would be justified absent the volatility.

Fortunately, there are several ways to help reduce potential CO₂ price volatility. The most direct way to mitigate CO₂ price volatility would be to use a carbon fee rather than cap and trade, though the latter approach appears more likely to be adopted in U.S. Under cap and trade, we suggest a safety valve mechanism that includes a slowly evolving price floor to protect investors as well as the more commonly discussed ceiling to protect customers. Tax benefits, development subsidies, and partial investment guarantees could also reduce risks and CO₂ price thresholds for investment.

High uncertainty in CO₂ policy and price levels could undermine the effectiveness and increase the cost of the climate policy. Although we agree with the caution that the government “should

not try to pick winners”, the potential inefficiencies from creating more favorable investment conditions targeted at capital-intensive carbon abatement technologies may be more than offset by the lost time, higher CO₂ emissions, and increased costs from waiting for the market to sort out the development risks by itself.

APPENDIX

ASSUMED GENERATION PARAMETERS IN 2020						
	Unit	SC Coal	IGCC	IGCC w/ Seq	CC	Nuclear
Overnight Cost	2008 \$/kW	2,647	3,047	4,017	931	5,250
ATWACC (Nominal)		10.70%	10.70%	10.70%	10.70%	10.70%
Capacity Charge Rate		13.00%	13.00%	13.00%	12.50%	14.00%
Heat Rate	Btu/kWh	8,528	7,968	9,382	6,377	10,170
Fuel Price	2008 \$/MMBtu	2.00	2.00	2.00	11.00	0.62
FOM	2008 \$/kW-yr	43.83	54.98	64.40	17.10	88.17
VOM	2008 \$/MWh	5.47	7.20	9.03	1.44	0.50
CO2 Transport and Storage	\$/tCO2			5.00	-	-
CO2 Rate - Captured	lb/MMBtu	-	-	177	-	-
CO2 Rate	lb/MMBtu	203	197	20	119	-
Capacity Factor		80%	80%	80%	80%	80%