

CO₂ Price Volatility: Consequences and Cures

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The Brattle Group provides consulting and expert testimony in economics, finance, and regulation to corporations, law firms, and governments around the world.

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Introduction

A number of current climate policy proposals in the U.S. involve a cap and trade mechanism with increasingly tight caps on carbon emissions over time. Most of the debate about how to pursue such a policy has focused on the level of the caps over time, how allowances will be auctioned or allocated, and what kinds of offsets should be allowed.

One aspect that is less often discussed but quite important to the success of climate policy is the potential for CO₂ price volatility and how it could be managed. High volatility in CO₂ prices could discourage and delay investment in the long-lived, capital-intensive CO₂ abatement technologies needed to achieve large reductions in carbon emissions.

In this paper, we assess the extent of volatility likely to surround long-run CO₂ prices under cap and trade proposals and its implications for CO₂ abatement. Our key findings are:

- ◆ *CO₂ price volatility is likely to be greater than currently suggested 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.*
- ◆ *By increasing investors' hurdle rates, making debt financing more difficult, and creating an option value for waiting to invest, CO₂ price volatility will cause CO₂ abatement technologies to be deferred for 10 years or more, until CO₂ prices are perhaps double the levels needed to justify these investments, absent the volatility. This effect is not incorporated in CO₂ price forecasting models.*
- ◆ *In order to mitigate volatility and foster investment, we recommend 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), along with other investment support mechanisms.*

CONTENTS

This paper discusses the climate policy proposals that aim for significant reductions in CO₂ emissions and how they will likely lead to highly volatile CO₂ prices. We identify the effects of CO₂ price volatility and explore how they create a substantial market barrier for the very investments that climate policies attempt to encourage.

Section 1 Volatile CO₂ Prices Likely Under a Cap and Trade Mechanism

Section 2 Impact of Volatile CO₂ Prices on CCS Investment

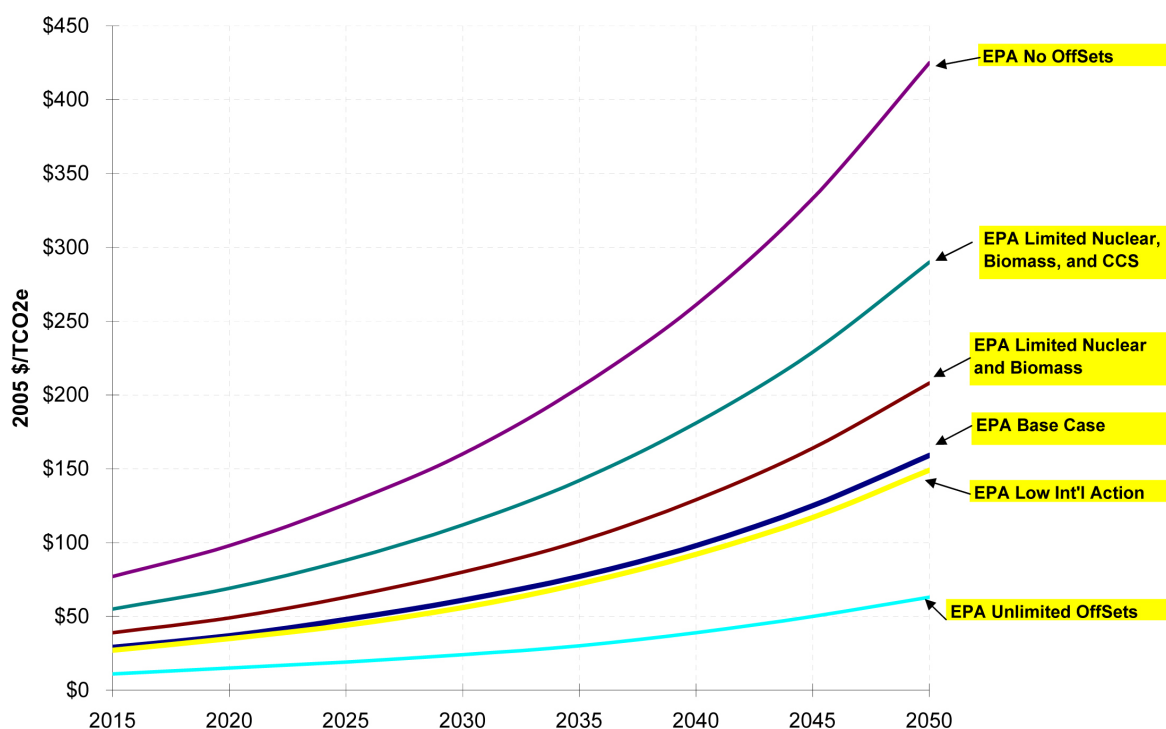
Section 3 Suggested Policies to Mitigate CO₂ Price Volatility

Section 1 | VOLATILE CO₂ PRICES LIKELY UNDER A CAP AND TRADE MECHANISM

Most of the climate policies proposed during the last several years in the U.S. are in the form of cap and trade systems placing increasingly restrictive limits (caps) on the allowed emissions of greenhouse gases (including CO₂). A recent and widely-discussed example to such climate policy proposals in the U.S. is “America’s Climate Security Act,” introduced by Senators Lieberman and Warner in October 2007. This proposal (which we will refer to as “L-W”) results in a CO₂ price set by the market (through auctions and CO₂ allowance trading) that will have to be paid by the emitters of greenhouse gases.

One important feature of L-W (that is also common in most of the cap and trade proposals) is that it does not include any floor or ceiling on CO₂ prices. Its targets for significant reductions in emissions, coupled with uncertainty in the factors affecting demand for allowances and cost of abatement, make it likely that CO₂ prices will be highly variable and uncertain.¹ Several government agencies (EIA and EPA), research centers (e.g., Nicholas Institute), and other organizations (e.g., the Clean Air Task Force and the American Council for Capital Formation) have conducted studies to estimate possible future CO₂ prices under L-W. As shown in Figure 1, EPA’s estimates vary significantly — by factors of two to four, or ±100% across analyses — due to differences in assumptions, uncertain demand for allowances, potential changes in energy efficiency, availability/cost of mitigating technologies, policy uncertainty, and availability and price of offsets.²

Figure 1 EPA GHG Allowance Price Scenarios Under Lieberman-Warner



1. L-W does include the ability to bank and borrow allowances, and this can be expected to mitigate the short-term and transient volatility, e.g., over a year or two. However, long-term volatility from persistent shifts in the demand for allowances and the cost/availability of abatement technologies would not likely be mitigated. See Fell, MacKenzie, and Pizer, “Prices versus Quantities versus Bankable Quantities,” Discussion Paper, *Resources for the Future* (July 2008).

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

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We calculated the standard deviation of CO₂ prices from projections in all of the studies listed above. The implied volatility (standard deviation) in L-W annual CO₂ prices ranges from \$21/ton (or 46% of the mean estimate of \$45/ton) in 2020 to \$100/ton (or 49% of the mean estimate of \$205/ton) in 2050.³ Some of this uncertainty will be reduced when the actual policy is adopted – though we doubt the policy will (or should) be articulated in an unchangeable form.

Even recognizing this, we believe it is likely that this estimate understates the true uncertainty surrounding future CO₂ prices, because the models for forecasting CO₂ prices typically use deterministic assumptions for major drivers of CO₂ prices, such as the price of natural gas or plant construction costs. Many of these factors are themselves highly uncertain. For example, during the period 1995-2008, the standard deviation of the annual average changes in 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 in 2009 had an annualized volatility of 38%. Since CO₂ prices for the first few decades will be sensitive to the competition between natural gas and coal-fired generation, the considerable uncertainty in those fuel and construction costs will be manifest in CO₂ price variability as well.⁴

Section 2 | IMPACT OF VOLATILE CO₂ PRICES ON CCS INVESTMENT

In order to isolate the effect of CO₂ price volatility on Carbon Capture and Sequestration (CCS) investment, we address the incremental costs and benefits of CCS relative to an Integrated Gasification Combined Cycle (IGCC) plant without CCS. Although IGCC with CCS is a technology that is still under development and has not yet been deployed, the cost of building an IGCC plant with and without CCS has been estimated in several studies. We assume that CCS adds about \$1000/kW 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 approximately \$2/MWh. We also assume it extracts 90% of the CO₂, which can be transported and stored for \$5/ton.⁵

Using these assumptions, the present value of the incremental revenue requirements of CCS (to cover the IGCC's full-life increased capital and operating expenses) is about \$2.5 million per MW (\$2.5 billion for a 1000 MW plant), or about a 30% increase in the costs of the IGCC plant. An investor must have reasonable confidence that this \$2.5 billion cost can be recouped via avoided CO₂ prices before making the CCS investment. For this to occur, ignoring the impact of uncertainty, CO₂ prices need to be \$30-35/ton. Of course, uncertainty will be present and will affect the investment decision. In the following, we demonstrate three ways in which risk aversion associated with CO₂ price volatility might be manifested and cause the required CO₂ break-even price to be much higher.

3. 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 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 that 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 correspondingly 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.

4. A more comprehensive version of this report, "Volatile CO₂ Prices Discourage CCS Investment," will be available at *The Brattle Group's* website www.brattle.com, which will present calculations showing how the uncertainty in fuel and construction costs are likely to be leveraged into greater uncertainty in CO₂ prices.

5. See the MIT study, "The Future of Coal" (2007) and recent cost estimates by the U.S. Federal Energy Regulatory Commission, "Increasing Costs in Electric Markets" (June 19, 2008) that reflect the significant rise in construction costs in the last few years.

CO₂ Price Volatility: Consequences and Cures**MECHANISM 1: HIGHER DISCOUNT RATE FOR AVOIDED CO₂ COSTS**

In evaluating future streams of revenues from any commodity or instrument, one key step is to determine the discount rate that reflects the riskiness of that asset relative to the rest of the economy (*i.e.*, systematic risk). The riskier the future net cash flows from owning an asset (or the revenues from selling a commodity) the higher the discount rate, hence the lower the present value (or equivalently, 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 macro-economic conditions. Experience to date in Europe already supports this expectation. Using historical CO₂ prices in the European Union Emission Trading Scheme (ETS), we estimate a CO₂ beta of about 0.65 and a resulting risk premium of about 3.0%.

We expect this risk premium over short-term government bills to be a lower estimate for the risk premium expected under L-W, since the systematic risk will likely be much higher under L-W than under the less stringent caps implemented in the ETS program so far. The total annual caps approved by the 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 2005.⁶

We calculated the minimum CO₂ price at which CCS becomes economic as a function of the discount rate. 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 economical.⁷ A 10% discount rate

moves the break-even up to about \$49/ton (within the range of typical estimates from other studies).⁸ At a 15% discount rate, the break-even CO₂ price increases to \$66/ton, more than double the required low-risk CO₂ price.

**MECHANISM 2: HIGHER REQUIRED CO₂ PRICE DUE TO RISK AVERSION AGAINST WORST-CASE INVESTMENT SITUATION**

Instead of increasing their hurdle rates in anticipation of CO₂ volatility, investors may respond to this risk through the use of deliberately conservative price estimates in their analysis of the investment. For example, some investors (especially lenders) may apply a “worst-case” standard by testing the investment against a lower-than-expected price for CO₂, *e.g.*, at the 10th percentile of its forecasted price distribution (that is, at a CO₂ price that provides a 90% likelihood of being exceeded) instead of at its expected value.

An illustration of this conservative approach is seen in Figure 2 on page 5. As discussed, we estimated a lower bound on the standard deviation of annual CO₂ prices under L-W to be 50%. Assuming a normal

6. 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> (accessed January 7, 2009).

7. Again, this CCS becomes economic on an IGCC that is itself assumed to be economic without the incremental CO₂ prices. This level of CCS break-even, at \$31/ton, is a bit below most estimates because it assumes a very low cost of capital.

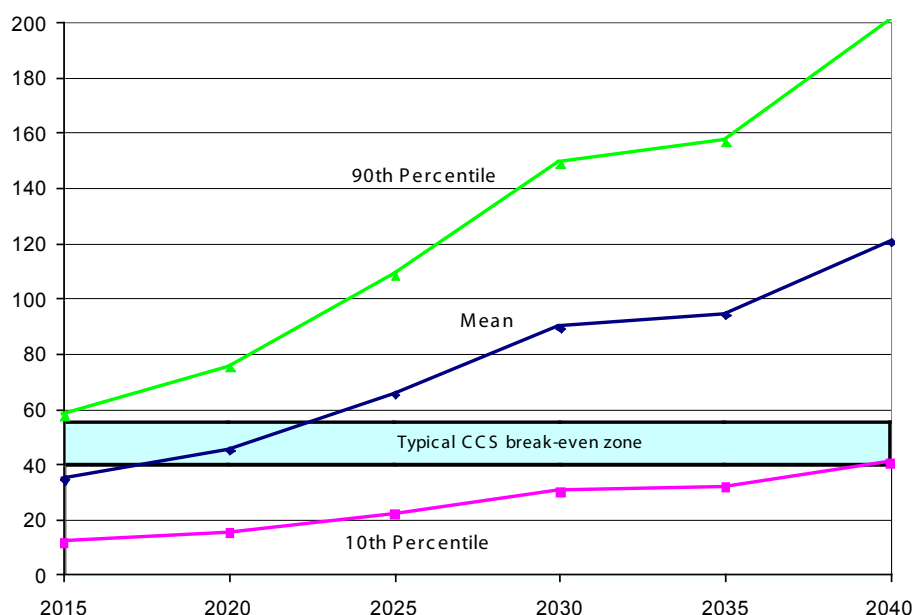
8. Avoided cost (or break-even price) of CCS was estimated to be between \$39-42/ton by the National Energy Technology Laboratory, “Cost and Performance Baseline for Fossil Energy Plants” (August 2007), between \$35-50/ton by McKinsey, “Carbon Capture & Storage: Assessing the Economics” (2008), and between \$25-40/ton by the IEA, “Capturing CO₂” (May 2007).

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distribution, CO₂ prices that are 1.3 standard deviations, or $\pm 65\%$, around the mean, will be at the 10th and 90th percentiles of cumulative probability.⁹

Applying these percentages to the average of the EPA's L-W CO₂ price estimates, 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. This level is achieved almost immediately by the average price curve, but it is 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 2 80% Confidence Interval for L-W CO₂ Prices



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

Most real asset investments can be made at various points in time, and the first point in time when an asset has a positive net present value (NPV) may not be the time when it would have its greatest NPV. If there is great uncertainty surrounding its future cash flows and there is only a modest cost of waiting a while, e.g., by incurring an operating penalty such as CO₂ allowance costs, it may be optimal to wait for more auspicious conditions.¹⁰ This allows the investor the possibility of avoiding the investment entirely if the underlying commodity determining the value of the asset should go down. The size and irreversible nature of investments in baseload, low-CO₂ technologies with large capital costs such as IGCC with CCS or nuclear generation, require a prudent investor to consider the value of waiting.

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

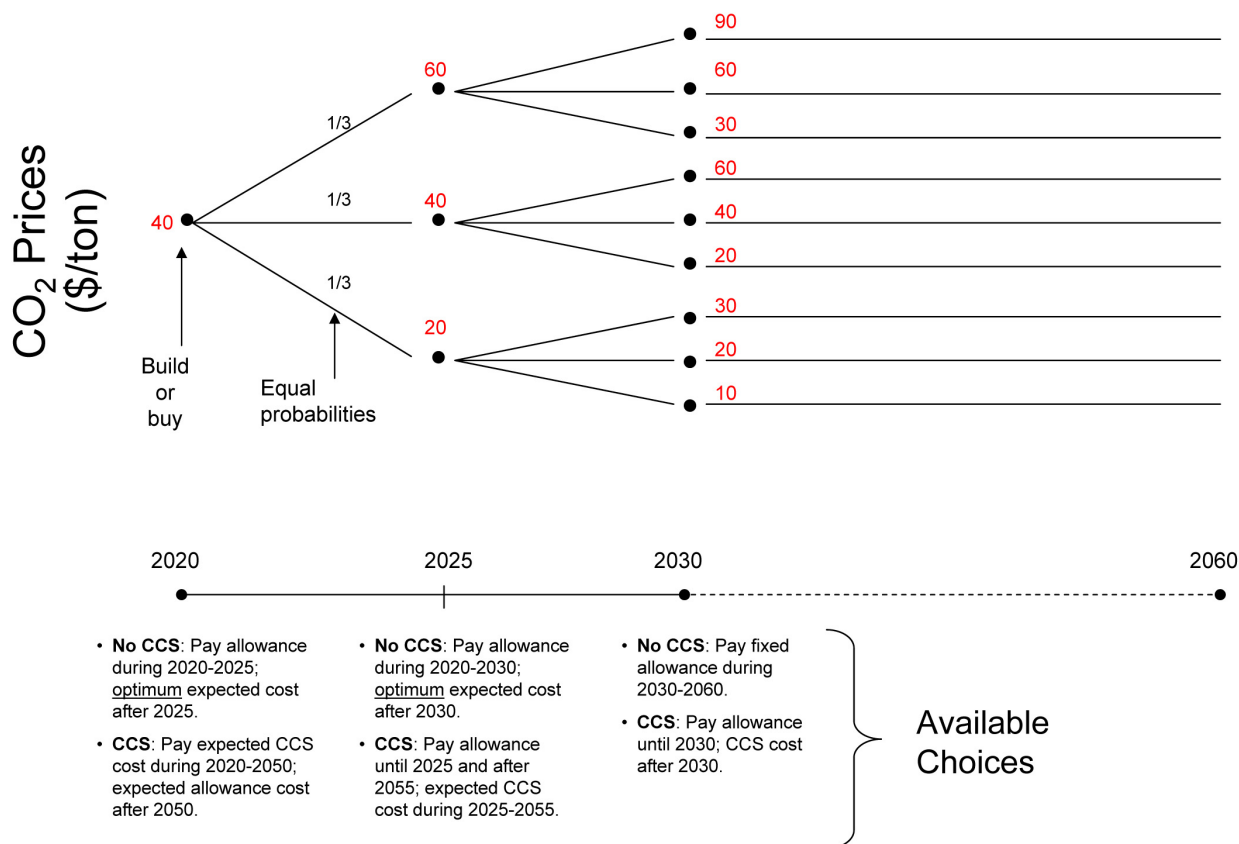
10. The financial economics literature has addressed this possibility extensively in its real options literature. See, for instance, Majd, and Pindyck, "Time to Build, Option Value, and Investment Decisions," Energy Laboratory Working Paper No. MIT-EL 85-011-WP (June 1985). Here, we illustrate the option value of waiting for CCS investment using a simplified, decision-analytic framework rather than formal option pricing techniques.

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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 of the future CO₂ allowance costs otherwise required for using the plant.¹¹ Assume that the economic life of the CCS component is 30 years. Imagine that the plant owner faces just three decision points in 5-year intervals starting in 2020. That is, 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. If not, the owner re-evaluates the CCS five years later.

To simplify the analysis, the year 2030 is assumed to be the last chance to build this 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. These choices are depicted below in Figure 3.

Figure 3 CO₂ Prices and Decision Points Under a High Volatility Case
(±50% Growth Every 5 Years)



11. CCS eliminates about 90% of the CO₂ that would otherwise be emitted by the IGCC.

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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 they either change in 5 years by $\pm 50\%$ or they remain the same, each possibility having an equal probability. With this price process, the CO₂ price in 2025 will be either higher (\$60/ton), the same (\$40/ton), or lower (\$20/ton). CO₂ prices branch again in 2030 in the same proportions with equal probabilities and are then in the range of \$10/ton to \$90/ton, where they are assumed to stay thereafter. Ignoring the impact of volatility on the option value of waiting, the \$40 price in 2020 would modestly justify investing in CCS, with a present value in 2020 of \$0.19 million per MW below the costs of not building, at a 7.5% real discount rate.

However, accounting for the option value of waiting under 50% volatility in CO₂ prices, the NPV of waiting optimally for up to ten years further reduces the 2020 present value by \$0.2 million per MW. Therefore, in this high volatility case, it is optimal to wait for building CCS (here, until 2025), even though the NPV of CCS will already be positive as early as 2020. Delay is attractive compared to just building in 2020 because this strategy avoids building in a few scenarios that could, by 2025, turn out to be unattractive.

In contrast, consider a low volatility case, in which prices can change by only $\pm 10\%$ at each 5-year interval. In this situation, CO₂ prices will be in the narrower range of \$32-48/ton in 2030 (versus \$10-90/ton range in the preceding 50% volatility case). Decreasing the volatility in CO₂ prices from 50% to 10% eliminates the option value of waiting such that it is now optimal to build in 2020. Lower volatility avoids delaying the CCS investment by 5 years. The table below summarizes the present value costs of the different investment timings and the net option value of waiting.

Value of Waiting for CCS Investment under High vs. Low CO₂ Price Volatility

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)

advantage to
waiting

disadvantage
to waiting

CO₂ Price Volatility: Consequences and Cures**SUMMARY OF IMPACTS OF CO₂ PRICE VOLATILITY ON BREAK-EVEN PRICE AND TIME TO BUILD**

The above examples show the plausibility of CCS not being economically attractive in light of likely CO₂ price volatility, until real CO₂ prices reach \$65-70/ton, rather than the conventionally estimated break-even levels around \$35-45/ton that ignore the effect of volatility. This means that CO₂ volatility could cause a delay of ten years or more in CCS adoption as summarized below.

Uncertainty Adjustment	Required CO ₂ price	Years of Delay
Higher Discount Rate		
• Low-risk utility (5%)	\$31/ton	0
• Merchant (15%)	\$66/ton	15 years
Worst-Case Scenario		
• 0%	\$31/ton	0
• 70%	\$71/ton	15 years
Optimal Waiting		
• 10%	\$38/ton	0
• 50%	\$46/ton	5 years

Section 3 | SUGGESTED POLICIES TO MITIGATE CO₂ PRICE VOLATILITY

The foregoing demonstrates that CO₂ price volatility could delay carbon abatement investments. This effect is not considered in most CO₂ forecasting models, so it is likely that the models understate the future prices of CO₂. 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 of the public discussion, it would still involve competitive market forces.¹²

Notwithstanding the potential advantages of a carbon fee approach, a cap and trade framework appears 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.

One option available to policy makers would be to use “safety valves” to limit the range on realized CO₂ prices. A ceiling to protect consumers is achieved by the government selling allowances at a stated price, if needed to satisfy a tight cap. A floor to protect investors could be achieved by the government buying back allowances if the price collapsed below a level that was deemed necessary, on average, to attract the next wave of mitigating technology and to provide some degree of revenue stability for deployments of long-lived, low-CO₂ technologies.

12. 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.

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Of course, a floor should not apply if a comprehensive, low-cost solution should happen to be developed. Thus, a floor cannot be fixed and left in place regardless of market circumstances. Rather, it should adjust slowly. 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. This problem is similar to the need for capacity markets now in effect in some wholesale electric markets in the U.S., which ensure resource adequacy by providing some degree of revenue stability for generation resources. CO₂ prices may need similar indirect management.

Alternatively, the cap on allowable CO₂ emissions could be tightened if and when it became apparent that it was going to be easier (cheaper) to achieve CO₂ reductions than had been expected. This would bring the prices up, protecting earlier investments. Finally, direct subsidies or tax breaks could be extended to critical technologies (like CCS), thereby lowering the break-even CO₂ price for their developers. If the scientific community concludes that there is an ecological upper bound on tolerable, cumulative global CO₂ emissions by 2050 that must be met regardless of investor preferences and risk averseness, then we will need to regulate the price and quantity of abatement technology development to reach those targets.

If CO₂-reducing technologies are delayed, CO₂-intensive technologies with long lives are likely to be installed instead, increasing emissions and creating a greater burden to solve the problem with even tighter caps in the future. Thus, early uncertainty in CO₂ policy and price levels could be costly.

It is commonplace when considering government regulation of a problem to argue that the government “should not pick winners”. We agree with that caution, and we are not advocating that the government select and favor particular technologies, even though our analysis has focused on CCS. Instead, we are suggesting that the government should design CO₂ capping and pricing mechanisms that make the investment climate relatively stable, especially initially. This will doubtless alter the market somewhat, but it is important to appreciate the large amount of investment and the potential urgency to invest that global warming presents.

The inefficiencies from protecting capital-intensive abatement technologies 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 climate policy and its operations over decades. Furthermore, we are likely to need every kind of approach that has a reasonable 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.

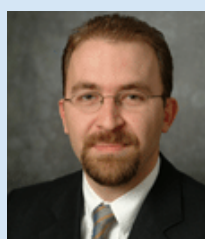
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Conclusion

We find that the extent of volatility likely to surround long-run CO₂ prices under cap and trade proposals is likely to be substantial, and is likely 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 likely deter investors' willingness to undertake long-lived, capital-intensive, and low-CO₂ technologies. CO₂ abatement technologies could be deferred many years due to price volatility, until CO₂ prices are perhaps double the levels where they 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.

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