Making the Cut with a Carbon Elimination Price: The Missing Piece to Bill Gates' *How to Avoid a Climate Disaster* Book

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Introduction

Bill Gates has a massive number of followers on LinkedIn—about 31 million and growing last I checked. His influence across the technology world is legendary as is his work on a myriad of charitable and philanthropic causes. Less well known is Gates' deep influence in one area of technology that we share a passion for: clean energy.

With that shared passion, it was with excitement that I read Gates' most recent book, *How to Avoid a Climate Disaster*. Let me start by saying that I appreciate the book, and overall, found it to be a good read. Gates assembled a lot of information and presents it in a digestible way; however, I finished the book feeling that Gates' call to action was missing one key element. Let me explain.

Gates starts his book with a very poignant statement:

> *"There are only two numbers you need to know about climate change. The first is 51 billion. The other is zero. Fifty-one billion is how many tons of greenhouse gases the world typically adds to the atmosphere every year. … Zero is what we need to aim for."*

He begins to address the issue of how much it will cost to achieve "zero" greenhouse emissions and introduces his concept of "Green Premiums":

> *"The reason the world emits so much greenhouse gas is that … our current energy technologies are by and large the cheapest ones available. … Most of these zero-carbon solutions are more expensive than their fossil-fuel counterparts. … These additional costs are what I call Green Premiums."*

Gates then goes on to explain "Green Premiums" as an expression of how much one lower-carbon option is going to cost compared to their fossil-fueled counterparts:

> *"Green Premiums are a fantastic lens for making decisions. … Which zero-carbon options should we be deploying now? Answer: the ones with a low Green Premium, or no premium at all. … Where do we need to focus our research and development spending? … Answer: wherever we decide Green Premiums are too high."*

Ultimately, to achieve zero carbon emissions, Gates argues that the goal is to reduce Green Premiums so that carbon reducing solutions can be adopted in an economical way. After finishing the book, the reader is left to wonder about prioritization, costs and where we should apply R&D dollars first. While Green Premiums are a good start, they are only partially helpful because they do not quantify carbon reduction costs by industry or process. Without a mechanism to calculate and compare costs by industry, the book leaves a gap in what could have been a clearer call to action.

What we need, and what I suggest in this paper, is a "Carbon Elimination Price" by industry. A Carbon Elimination Price could help us prioritize decarbonization efforts so that we achieve zero carbon emissions at the lowest cost and with the most efficient use of limited R&D dollars. This paper includes illustrative examples that show how Carbon Elimination Pricing would be calculated. As an example, I demonstrate how focusing efforts on electric vehicles could result in a net savings, while other forms of transportation such as ships or airplanes have a much higher Carbon Elimination price.

My hope is that this paper can prompt Gates and other influencers in the wider clean energy space to think not just about defining "green premiums," but also how we proceed to de-carbonize and where we should focus resources today to achieve our common goals.

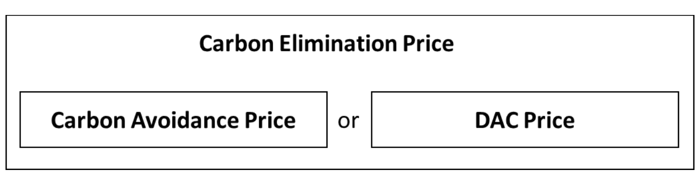
Carbon Elimination Price

One can reduce carbon emissions by avoiding them before they occur or by removing them after they have been produced. Consider several prices that combine the cost of reducing emissions with the amount of carbon savings.

- Carbon Avoidance Price. Carbon Avoidance Price is the price of avoiding emissions before they occur. *We define Carbon Avoidance Price as the Green Premium divided by the carbon savings.* This is the price that combines Green Premiums with the associated carbon savings. It allows us to compare prices across all industries and applications.
- Direct Air Capture (DAC) Price. DAC Price is the price of removing emissions after they occur. DAC Price is a term used by Gates in his book.
- Carbon Elimination Price. The most economical solution to eliminating carbon emissions is to select the option with the lowest price. We define the Carbon Elimination Price as the lesser value between Carbon Avoidance Price and DAC Price.

Figure 1. Carbon Elimination Price is the minimum of the Carbon Avoidance Price and the DAC Price

Carbon Elimination Price = minimum (Carbon Avoidance Price, DAC Price)



Note that a typical economic solution to a product with a negative externality is to charge the producer a price equal to the monetary value of the damage caused by the emissions. This is the societal cost of carbon.[1] The Carbon Elimination Price is fundamentally different from the societal cost of carbon because it solves the problem directly rather than charges the carbon emitter to compensate for the negative consequences. In addition, there are many Carbon Elimination Prices because they are industry and application specific while there is one price for the social cost of carbon.

Carbon Elimination Price Example

We can use data from Gates' book to illustrate how to put these prices to work. More specifically, we can calculate the Carbon Elimination Price for each category and subcategory listed by Gates. The following example is not meant to be conclusive about the exact prices. Rather, it is intended to illustrate how to use Carbon Elimination Prices. Further work is required to refine the numbers.

Carbon Elimination Price is calculated in two steps.

Step 1. Calculate Carbon Avoidance Price
Step 2. Calculate Carbon Elimination Price

Consider how much carbon is emitted by industry and subcategory within the industry. Gates lists the greenhouse gases emitted in the world by the "Things we do" on page 55. The breakdown of the "Getting around" category is listed on page 134. Unfortunately, the book does not breakdown "Making things" into subcategories so we will just assume an equal distribution for this category.

Table 1. Emissions by Subcategory

Category	% of Total	Subcategory	% of Category	Emissions (Billion Tons per year)
Making things	31%	Ethylene	33%	5.3
		Steel	33%	5.3
		Cement	33%	5.3
Plugging in	27%			13.8
Growing things	19%			9.7
Getting around	16%	Cars	47%	3.8
		Trucks	30%	2.4
		Ships	10%	0.8
		Airplanes	10%	0.8
		Other	3%	0.2
Keeping warm and cool	7%			3.6
Total				51.0

[1] The externality-based approach is discussed on many websites. Here are a few examples. https://en.wikipedia.org/wiki/Carbon_price; https://carbonpricingdashboard.worldbank.org/what-carbon-pricing; https://www.worldbank.org/en/programs/pricing-carbon.

Now that we have emissions by category and subcategory, we can examine the Green Premiums and the associated emissions reductions. First, we calculate the Carbon Avoidance Price. Table 2 presents the data and calculations. The second column is the emissions (from Table 1). The third column is the Green Premium. The fourth column is the emissions reduction. The final column is the Carbon Avoidance Price. The footnotes identify where the data come from in Gates' book and document assumptions when the data was unavailable in the book.

Table 2. Carbon Avoidance Price

	World Emissions (Billion Tons per year)	Green Premium	Emissions Reduction	Carbon Avoidance Price
Making things (Ethylene)	5.3	$121 per Ton Material[2]	1.3 Ton CO_2 per Ton Material[2]	$93 per Ton
Making things (Steel)	5.3	$168 per Ton Material[2]	1.8 Ton CO_2 per Ton Material[2]	$93 per Ton
Making things (Cement)	5.3	$135 per Ton Material[2]	1.0 Ton CO_2 per Ton Material[2]	$135 per Ton
Plugging in	13.8	$0.015 per kWh[3]	0.92 lbs CO_2 per kWh[4]	$36 per Ton
Growing things	9.7			$100 per Ton[5]
Getting around (Cars)	3.8	$2.57 per gallon[6]	20 lbs CO_2 per gallon[4]	$283 per Ton
Getting around (Trucks)	2.4	$2.79 per gallon[6]	20 lbs CO_2 per gallon[4]	$307 per Ton
Getting around (Ships)	0.8	$4.21 per gallon[6]	20 lbs CO_2 per gallon[4]	$463 per Ton
Getting around (Airplanes)	0.8	$3.13 per gallon[6]	21 lbs CO_2 per gallon[4]	$328 per Ton
Getting around (Other)	0.2	$2.57 per gallon[6]	20 lbs CO_2 per gallon[4]	$283 per Ton
Keeping warm and cool	3.6	($250 per Unit)[7]	2.0 ton CO_2 per unit[8]	($122 per Ton)

Next, we calculate the Carbon Elimination Price by choosing the lower price of the Carbon Avoidance Price and the DAC Price. Again, DAC is how much it would cost to "just suck the carbon out of the atmosphere directly." After all, the economically optimal approach is to spend up to the amount it would cost to directly capture the carbon after it has been emitted, but no more than this cost. The DAC price equals $100 per Ton (page 63). Table 3 presents the Carbon Elimination Price, sorted by Carbon Avoidance Price.

[2] Green Premium equals the average of Green Premium Range times the Average price per ton and carbon emitted per ton of material is taken from table directly (page 107).
[3] Zero-carbon premium for America is average of 1.3 and 1.7 cents per kWh (page 72).
[4] Source for CO_2 emissions in U.S. Electricity: 0.92 lbs CO_2 per kWh (https://www.eia.gov/tools/faqs/faq.php?id=74&t=11). Gasoline: 20 lbs CO_2 per gallon; Natural gas: 12 lbs CO_2 per therm; and Jet fuel: 21 lbs CO_2 per therm (https://www.eia.gov/environment/emissions/co2_vol_mass.php).
[5] Detailed data were not available in the book to perform the required calculation. Use the DAC price of $100 per Ton (page 63).
[6] Zero-carbon option per gallon minus retail price per gallon (page 144).
[7] Take the average of all the Green Premiums and then divide by 10 to convert to annual values (page 154).
[8] Assumption that average home consumes 750 therms per year and will consume 4,900 kWh per year after installation of heat pump. Emissions reduction equals 750 therms * 12 lbs CO_2 per therm minus 4,900 kWh * 0.92 lbs CO_2 per kWh. Multiply by 1 Ton per 2200 lbs.

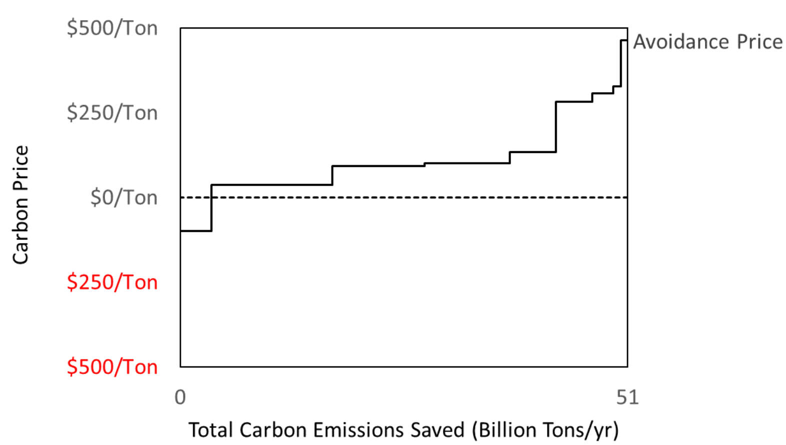
Table 3. Sorted Carbon Elimination Price.

	World Emissions (Billion Tons per year)	Carbon Avoidance Price	Carbon Elimination Price
Keeping warm and cool	3.6	($122 per Ton)	($122 per Ton)
Plugging in	13.8	$36 per Ton	$36 per Ton
Making things (Steel)	5.3	$93 per Ton	$93 per Ton
Making things (Ethylene)	5.3	$93 per Ton	$93 per Ton
Growing things	9.7	$100 per Ton	$100 per Ton
Making things (Cement)	5.3	$135 per Ton	$100 per Ton
Getting around (Cars)	3.8	$283 per Ton	$100 per Ton
Getting around (Other)	0.2	$283 per Ton	$100 per Ton
Getting around (Trucks)	2.4	$307 per Ton	$100 per Ton
Getting around (Airplanes)	0.8	$328 per Ton	$100 per Ton
Getting around (Ships)	0.8	$463 per Ton	$100 per Ton

Results

We are now ready to visualize results. *Figure 1* presents Carbon Avoidance Price versus the total carbon emissions saved. The total cost using the Carbon Avoidance Prices equals $5.3 trillion per year. This is almost the same as the cost identified by Gates if we used only DAC to capture the emissions.

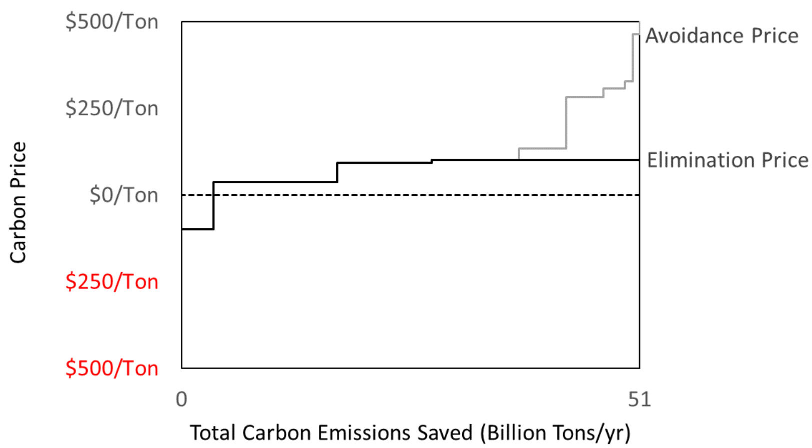
Figure 2. Carbon Avoidance Price vs. Total Carbon Emissions Saved
Total Annual Cost = $5.3 trillion/year



As suggested above, however, a more economical approach would be to only switch technologies if the price of reducing carbon before it is emitted is less than the price of capturing the carbon after it has been emitted—the DAC Price. That is, it equals the minimum of the Carbon Avoidance Price and the DAC Price.

Figure 2 presents the results. The total cost using the Carbon Elimination Price is $3.4 trillion per year.

Figure 3. Carbon Prices vs. Total Carbon Emissions Saved
Total Cost = $3.4 trillion/year



Putting Carbon Elimination Prices to Work

Let's show how we can put the Carbon Elimination Price to work by illustrating the dramatic effect a change in assumptions can have. While the objective is not to give a precise calculation of the cost of transitioning to zero emissions, we can demonstrate how the Carbon Elimination Price can be useful by looking at the "Getting around (Cars)" category in Gates' new book as an example.

Gates lists several options to eliminate emissions produced by operating cars. In our example, we'll consider EVs and biofuel cars.

- EVs – According to Gates, "Although EVs used to be far more expensive than their gas-burning counterparts, and they're still the pricier option today, the difference has come down dramatically in recent years (page 135)." Gates then states that there is a 10-cent per mile Green Premium for an EV over a gas-powered vehicle (page 136). This translates to a Green Premium of 17% if the 10-cent premium is relative to the 57.5 cents per mile 2020 IRS allowable tax-deductible rate.[9] "What does 10 cents a mile mean? If you drive 12,000 miles a year, that is an annual premium of $1,200."

- Advanced biofuels – The Green Premium for biofuels is 106% of the $2.43 retail price per gallon, or $2.57 per gallon. This has an annual premium of $752 for a car that is driven 12,000 miles per year[10] and gets the current CAFE standard of 41 miles per gallon.[11]

Advanced biofuels were selected for use in *Table 2* over EVs since $752 is less than $1,200. From a Carbon Elimination Price perspective (i.e., the minimum of the Carbon Avoidance Price and the DAC Price), the DAC Price of $100 per ton applies because it is less than the advanced biofuels Carbon Avoidance Price of $283/ton.

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[9] https://www.irs.gov/tax-professionals/standard-mileage-rates.
[10] $752 per year = $2.57 per gallon * (12,000 miles per year / 41 MPG).
[11] The current CAFE standard for passenger cars is between 40.3 and 41 MPG. https://www.transportation.gov/mission/sustainability/corporate-average-fuel-economy-cafe-standards.

Suppose that extensive R&D investments reduced the advanced biofuels Green Premiums from the current value of 106% down to 38% so that they only cost $0.92 per gallon more than the retail price of gasoline. The Carbon Avoidance Price would be $101 per Ton.[12] Since this is still higher than the DAC Price, the Green Premium reduction would have no effect on the total cost of reducing emissions because DAC would still be less expensive than advanced biofuels.

Alternatively, consider the EV option. An EV will reduce emissions by 0.25 lbs CO_2 per mile.[13] This translates to a Carbon Avoidance Price of $880 per Ton.[14] This would have made EVs have the highest price sector in Table 2. Thus, the Carbon Elimination Price remains at $100 per Ton.

Multiple writers, however, have made the argument that EVs already cost less (not more) to drive than gas-powered vehicles when the reduced maintenance and longer vehicle life are considered, even excluding incentives. Cleanerwatt makes a particularly clear presentation of the 5-year cost of ownership.[15] They conclude that a popular EV will cost 17-cents less per mile than a comparable car. Furthermore, the absolute cost per mile is 13.5 cents less than the approved IRS rate, even though the car is a luxury vehicle. Thus, a very conservative estimate is that EVs will cost 5 cents per mile *less* to drive.

This translates to a Carbon Avoidance Price of -$440 per Ton.[16] As illustrated in *Figure 3*, Cars move from the most expensive subcategory to the subcategory that saves the most money. The total cost of reducing emissions is now $1.7 trillion per year. In fact, if the EVs save $0.10 per mile, there would be net *savings* by reducing emissions to zero because the EVs would save so much money.

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[12] $101 per Ton = ($0.92 per gallon / 20 lbs CO_2 per gallon) * (2,200 lbs per Ton).

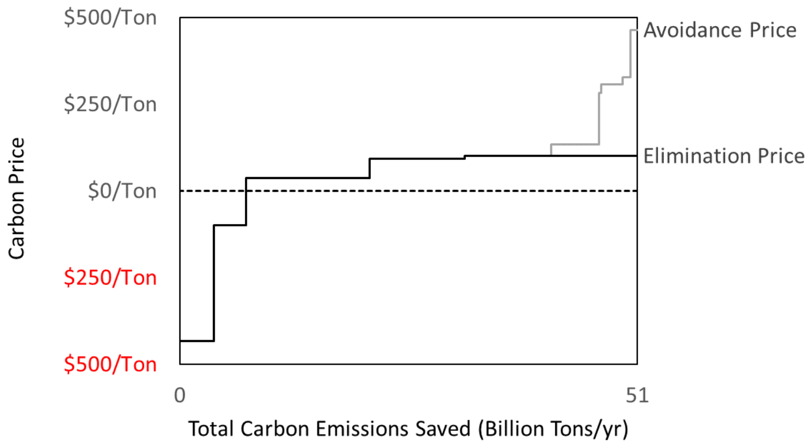
[13] Assume that the gas-powered vehicle gets the current CAFE standard mileage and the EV is the most popular one sold in the world (Tesla Model 3). The Model 3 gets 131 MPGe, which translates to 0.26 kWh per mile (https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=42277). Emissions reduction equals emissions for the gas-powered vehicle minus emission for the EV. Emissions for the gas-powered vehicle equals 20 lbs CO_2 per gallon divided by 41 MPG, or 0.49 lbs CO_2 per mile. Emissions for the EV equals 0.92 lbs CO_2 per kWh * 0.26 kWh per mile, or 0.24 lbs CO_2 per mile. The difference between the two is 0.25 lbs CO_2 per mile.

[14] $880 per Ton = ($0.10 per mile / 0.25 lbs CO_2 per mile) * (2,200 lbs per Ton).

[15] Cleanerwatt presents 5-year cost of ownership evaluations comparing EVs to non-EVs. They exclude incentives are from the analysis. One analysis compares the Tesla Model 3 Standard Range+ to a Lexus ES 300h (https://www.youtube.com/watch?v=W0dQe-KvPqE). The Tesla costs $0.17 less per mile than the Lexus ($0.44 per mile vs. $0.61 per mile). Even when the Tesla is compared to a Honda Accord Ex Hybrid, a car that has a purchase price that is $10K less than the Tesla, the two come out to have the same cost per mile (https://www.youtube.com/watch?v=YUn8_WKqZPA). Even when compared to allowable mileage rate set by the IRS, there is at least a savings of $0.10 per mile. Thus, a very conservative estimate is that EVs will save $0.05 per mile.

[16] -$440 per Ton = (-$0.05 per mile / 0.25 lbs CO_2 per mile) * (2,200 lbs per Ton).

Figure 4. Carbon Price with EVs that Save 5 Cents Per Mile.
Total Cost = $1.7 trillion/year.



Conclusions

Carbon Elimination Pricing is a useful metric as we approach the problem of transitioning to zero carbon emissions. Carbon Elimination Prices could help us prioritize our efforts so that we achieve zero emissions at the lowest possible cost by guiding our allocation of implementation and R&D investments.

The next steps of Gates' latest book could be to refine the Green Premium estimates and the carbon reductions associated with those premiums. It would also be useful to break results into a finer categorization. This could help us prioritize emissions reduction efforts from both implementation and R&D perspectives.