

“WEDGES”: EARLY MITIGATION WITH FAMILIAR TECHNOLOGY

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Abstract

If the world is willing to accept a tripling of the pre-industrial atmospheric CO₂ concentration, significant carbon mitigation can be delayed for most of the next half century. If the world is to be put on a path to avoid a doubling, however, a monumental mitigation effort needs to start now. To convey the magnitude of the effort, we introduce the “wedge” as the unit of mitigation: a wedge is an activity that creates 1 GtC/y of carbon emission reductions in 2054, relative to a world unconcerned about global carbon emissions. To pursue 500 ppm stabilization, the task for the next 50 years is to achieve about seven wedges by avoiding about 175 billion tons of carbon emissions.

The Stabilization Triangle

Figure 1 presents the Stabilization Triangle, a simple geometric idealization of global carbon management [1]. The Stabilization Triangle is intended to facilitate discussion of the single most critical question: *Why start now?*

Imagine that, at present, we confront a fork in the road where we can follow one of only two paths:

1. A “flat” trajectory, or “Act Now” trajectory, constant at the current emissions rate of 7 GtC/y until 2054.
2. A “ramp” trajectory, or “Delay” trajectory: This trajectory grows linearly at 2%/year from the current emissions rate of 7 GtC/y until it exactly doubles to 14 GtC/y in 2054.

[Figure 1 goes here.]

Figure 1 shows plausible extensions of the flat and ramp trajectories into stabilization trajectories. Each trajectory is the first of four 50-year segments of a 200-year relay race, leading to stabilization at 500 ppm and 850 ppm, respectively (less than doubling versus tripling the pre-industrial concentration of 280 ppm). To achieve 500 ppm, the first runner sustains constant emissions until passing the baton in 2054. The second runner reduces emissions until, in 2104, net emissions are zero: fossil fuel emissions exactly equal the sum of land plus ocean sinks. The third runner retains zero net emissions from 2104 to 2154, as the total sink falls, and the fourth runner retains zero net emission from 2154 to 2204, as the total sink falls further. By contrast, to achieve 850 ppm, the first runner accepts a doubling of emissions, the second runner holds emissions constant (at 14 GtC/y), the third runner brings emissions down until net emissions are zero, and the fourth runner keeps net emissions at zero. The assignments of the second, third, and fourth runners for 850 ppm stabilization match those of the first, second, and third runners for 500 ppm stabilization.

The fifty-year time frame, we believe, has much to recommend it. It is long enough to allow dramatic changes, and it is short enough to engage the world’s doers. We call the ramp trajectory the “Delay” trajectory because it is deep within the cloud of “Business As Usual” (BAU) scenarios for fifty years [2]. We call the flat trajectory the “Act Now” trajectory, because it is a simple model of rapid departure from BAU.

For Figure 1 we assume the future net land sink (uptake minus deforestation) is constant at 0.5 GtC/y [1]; this sink could be either stronger from carbon fertilization or weaker (even, a net source) from positive biological feedback effects, like peat decomposition. The ocean sink, using the HILDA Model [3], is 2.2 GtC/y today. It is 2.8 GtC/y, 1.9 GtC/y, 1.5 GtC/y, and 1.3 GtC/y in 2054, 2104, 2154, and 2204, respectively, for 500 ppm stabilization. For 850 ppm stabilization, the four corresponding values are 4.1 GtC/y, 4.4 GtC/y, 3.2 GtC/y, and 2.5 GtC/y.

Thus, Figure 1 highlights the intimate connection between the goal of stabilization and the urgency of action. Settle for tripling, and significant action can be delayed for most of the next half century. Insist on avoiding doubling, and work needs to begin now. John Browne, the head of BP, summarizing the options, writes: “A growing number of governments and experts have concluded that policy should aim to stabilize concentrations of carbon dioxide in the atmosphere in the range from 500 to 550 ppm over the next century”[4].

The Wedge as the Unit of Global Carbon Mitigation

How far can the first runner advance the baton? We assert that the first runner can keep carbon emissions flat. To do so requires the successful completion of several independent monumental tasks. We explain by partitioning the Stabilization Triangle into seven “wedges,” as seen in Figure 2.

[Figure 2 goes here]

A wedge is fifty years of mitigation activity which grows linearly from zero today to 1 GtC/y in 2054, avoiding 25 GtC of emissions. We recommend the “wedge” as a useful unit of activity for visualizing carbon management. Many carbon mitigation strategies cannot plausibly

grow large enough to provide a whole wedge. However, a full wedge or more is available for several mitigation strategies. Setting wedges side by side can clarify tradeoffs.

The Wedge as the Scale-up of Familiar Technology

In Table 1 each row describes a level of displacement in 2054 of one technology by another equal to one wedge: 2 million 1 MW-peak windmills, for example, displacing 700 efficient baseload coal plants; 800 efficient baseload coal plants capturing and storing CO₂, that would otherwise be vented; two billion vehicles achieving 60 mpg, instead of 30 mpg. The Stabilization Triangle can be filled with many combinations of wedges, including more than one wedge of the same activity. For more detail, see [1].

With few exceptions the wedges presented in Table 1 involve familiar technology. Often, somewhere in the world a large commercial program is in place: the sugar-to-ethanol program in Brazil, the Sasol coal-to-liquids program in South Africa, and the carbon capture and storage program at the Sleipner field in Norway are examples. A key conclusion from Table 1 is that fundamental breakthroughs are not required to make dramatic progress toward CO₂ stabilization in the 500 ppm range.

For a candidate for a wedge actually to be counted as a wedge, two things must be true. First, the substitution cannot already be part of Business As Usual. Every reader will reject some particular wedge, certain that the corresponding deployment will occur even with no climate strategy – but readers will disagree about which wedges to reject on such grounds. Second, one must not do double-counting; in the examples above, the 700 coal plants displaced by wind must not include any of the 800 coal plants whose CO₂ emissions are captured and stored.

Wedge analysis reveals that it is harder to decarbonize fuel than electric power. Yet today, power production creates only 40% of CO₂ emissions. Probably, in a carbon-constrained world, decarbonized electricity will invade fuels markets. Heat pumps will do more space and water heating. Grid-charged batteries will power hybrid vehicles.

Conclusions

Achieving a flat trajectory for the next 50 years puts stabilization at 500 ppm within reach. It requires greatly scaling up several known technological approaches, but it does not require fundamental breakthroughs.

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References

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[Table 1 goes here, occupying the full fourth page.]

Table 1. A Table of Wedges: Strategies available to reduce the carbon emission rate in 2054 by 1 GtC/y, or to reduce 2004-2054 carbon emissions by 25 GtC.

	Option	Effort by 2054 for one wedge, relative to 14 GtC/year BAU	Comments, issues
Energy Efficiency and Conservation	Economy-wide carbon-intensity reduction (emissions/\$GDP)	Increase reduction by additional 0.15% per year (e.g., increase U.S. goal of reduction of 1.96% per year to 2.11% per year)	Can be tuned by carbon policy
	1. Efficient vehicles	Increase fuel economy for 2 billion cars from 30 to 60 mpg	Car size, power
	2. Reduced use of vehicles	Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5,000 miles per year	Urban design, mass transit, telecommuting
	3. Efficient buildings	Cut carbon emissions by one-fourth in buildings and appliances projected for 2054	Weak incentives
	4. Efficient baseload coal plants	Produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today)	Advanced high-temperature materials
Fuel shift	5. Gas baseload power for coal baseload power	Replace 1400 GW 50%-efficient coal plants with gas plants (4 times the current production of gas-based power)	Competing demands for natural gas
CO ₂ Capture and Storage (CCS)	6. Capture CO ₂ at baseload power plant	Introduce CCS at 800 GW coal or 1600 GW natural gas (compared with 1060 GW coal in 1999)	Technology already in use for H ₂ production
	7. Capture CO ₂ at H ₂ plant	Introduce CCS at plants producing 250 Mth ₂ /year from coal or 500 Mth ₂ /year from natural gas (compared with 40 Mth ₂ /year today from all sources)	H ₂ safety, infrastructure
	8. Capture CO ₂ at coal-to-synfuels plant	Introduce CCS at synfuels plants producing 30 million barrels per day from coal (200 times Sasol), if half of feedstock carbon is available for capture	Increased CO ₂ emissions, if synfuels are produced <i>without</i> CCS
	Geological storage	Create 3500 Sleipners	Durable storage, successful permitting
Nuclear Fission	9. Nuclear power for coal power	Add 700 GW (twice the current capacity)	Nuclear proliferation, terrorism, waste
Renewable Electricity and Fuels	10. Wind power for coal power	Add 2 million 1-MW-peak windmills (50 times the current capacity) "occupying" 30x10 ⁶ ha, on land or off shore	Multiple uses of land because windmills are widely spaced
	11. PV power for coal power	Add 2000 GW-peak PV (700 times the current capacity) on 2x10 ⁶ ha	PV production cost
	12. Wind H ₂ in fuel-cell car for gasoline in hybrid car	Add 4 million 1-MW-peak windmills (100 times the current capacity)	H ₂ safety, infrastructure
	13. Biomass fuel for fossil fuel	Add 100 times the current Brazil or U.S. ethanol production, with the use of 250 x10 ⁶ ha (1/6 of world cropland)	Biodiversity, competing land use
Forests and Agricultural Soils	14. Reduced deforestation, plus reforestation, afforestation and new plantations.	Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 Mha of new tree plantations (twice the current rate)	Land demands of agriculture, benefits to biodiversity from reduced deforestation
	15. Conservation tillage	Apply to all cropland (10 times the current usage)	Reversibility, verification

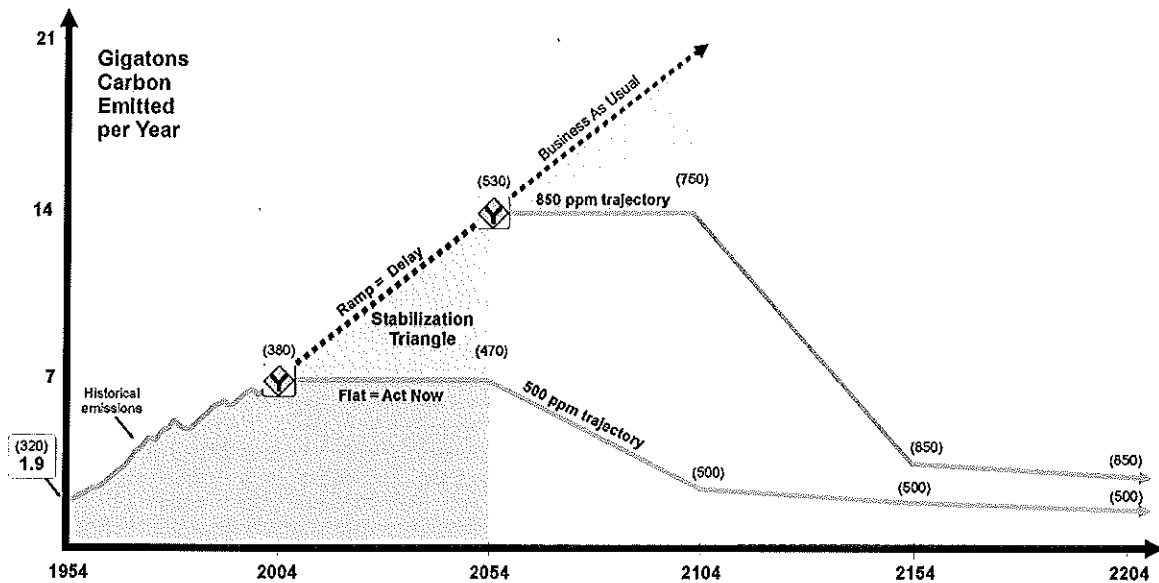


Figure 1: The Stabilization Triangle focuses attention on the choice between two paths for the next fifty years: 1) a path consistent with stabilization at less than double the pre-industrial CO₂ concentration (500 ppm), 2) a path that is likely to lead to tripling of that concentration (850 ppm). A representative "Business As Usual" (BAU) trajectory is also shown: the choice represented by the Stabilization Triangle is between immediate departure from BAU and postponement of departure from BAU for at least fifty years. Atmospheric CO₂ concentrations are in parentheses.

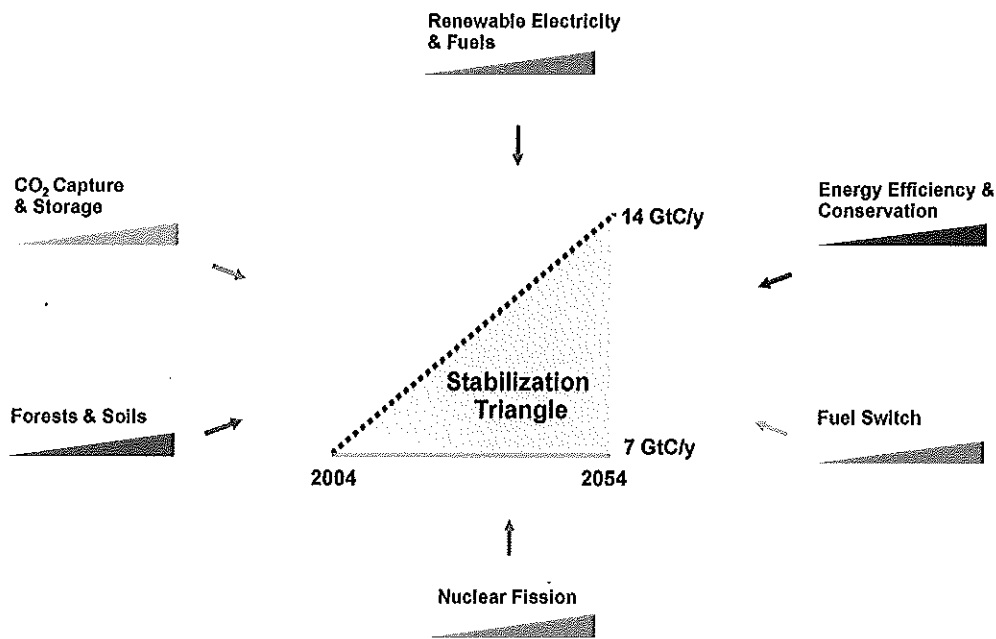


Figure 2: Filling the Stabilization Triangle with seven "wedges." Six broad categories are identified.