The Critical Role of Energy Efficiency in Mitigating Global Warming

By Robert Socolow

Public Service Commission, State of New York Proceeding on Motion of the Commission Regarding an Energy Efficiency Portfolio Standard

Albany Law School, Albany, New York, July 19, 2007

The following is a written version of the lecture presented by Professor Socolow at a meeting of the New York Public Service Commission on July 19, 2007.[1]

Thank you. I'm really thrilled to be here. This is the first talk in the first event of what may turn out to be a truly globally significant initiative on the part of New York State. I hope you can really make a difference by getting energy efficiency to the top of the list of ways in which we attack what's wrong with our current energy system.

It's been a passion of mine, the energy efficiency game. It became, and was, very exciting in the 1970s and 80s. There aren't many veterans of that early effort in this room, but fortunately, a few of us are still kicking who were part of all that. Dick Ottinger, congressman from New York State, from Westchester, was a national leader in the field and taught me a lot. Maybe people want to hear again what we think we figured out and then do it better.

So it's because you're attacking energy efficiency in this meeting that I said I'm going to just be here; if I'm invited, I'm going to come.

Past, Present, and Potential Future Levels of Carbon in the Atmosphere

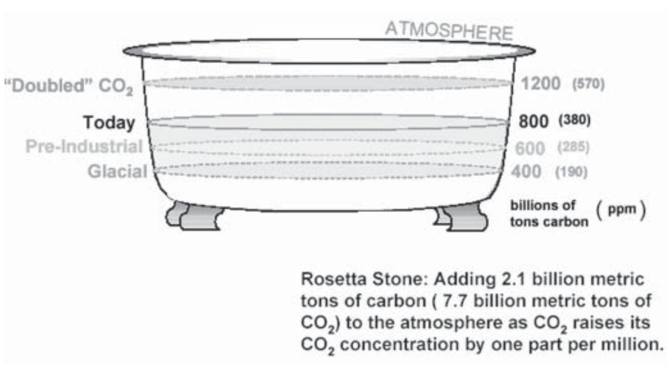


Figure 1

I'm going to start, though, with the biggest picture.

Past, Present, and Potential Future Levels of Carbon in the Atmosphere

The atmosphere can be thought of as a bathtub (Figure 1), and it's not that complicated a place. There's a certain amount of carbon in the atmosphere today. One of the wonderful things about this new way of casting the problem is we are considering the whole earth. It's our earth; it has certain properties. Its atmosphere has, in fact, 800 billion tons of carbon in it right now. Two hundred years ago, it had 600 billion tons of carbon in it. In the depths of the ice age, approximately 20,000 years ago, it had about 400 billion tons of carbon in it.

If you look through the ice-core records, it goes back and forth between 400 and 600 billion tons of carbon in about 100,000 year cycles, which is the ice-age cycle. We can learn about these cycles from ice cores drilled into the Antarctic ice sheet.

Six hundred is the reference number people use when they refer to future carbon. It's called the pre-industrial concentration or the pre-industrial quantity, and people talk about doubling or tripling it. When they just say doubling, that's what they mean. That's 1,200 billion tons of carbon in the atmosphere. From those numbers, you can see that at the present time we are both as far above the pre-industrial level as the depths of the ice ages were below, and one-third of the way to doubling. That is where we are, in this generation, as of the date of this meeting.

There happens to be another unit that people use to talk about carbon in the atmosphere. It is exactly proportional to the unit I've just explained, and it certainly confuses the conversation that we have two such units. This other unit is the fraction of the molecules in the atmosphere at this moment that are carbon dioxide molecules. It is 380 out of every million. When we're breathing right now, 380 molecules of carbon dioxide come in with each million molecules of air entering into our lungs. That number was about 285 in the pre-industrial period. The connection between the two units is 2.1 billion tons of carbon in the atmosphere equates to a part per million.

There's still a third unit: tons of carbon dioxide. Most of the prices that we talk about in the discussions of the economics of carbon are dollars per ton of carbon dioxide, not dollars per ton of carbon.

So there are three units. They're all proportional, just like miles, feet, and meters. When you have a carbon atom, you have two oxygen atoms attached; if it's carbon dioxide then that's a ratio of 44 to 12, because a carbon atom weighs in at 12 and an oxygen atom at 16. These relationships are part of the lingo of this subject. It takes a while to become comfortable, but there's nothing very difficult going on here.

The ice core records are a marvelous piece of science. When we drill an ice core in the Antarctic, it's just like drilling into a tree to examine the tree rings; the deeper you go, the further back in the past you are. Bubbles are trapped in there. That's allowed us to reconstruct about a half-million years of history in considerable detail and discover what the atmosphere was like in the past, and what's going into that bathtub and what's going out. (Figure 2)

About Half of the Carbon We Burn Stays in the Atmosphere for Centuries

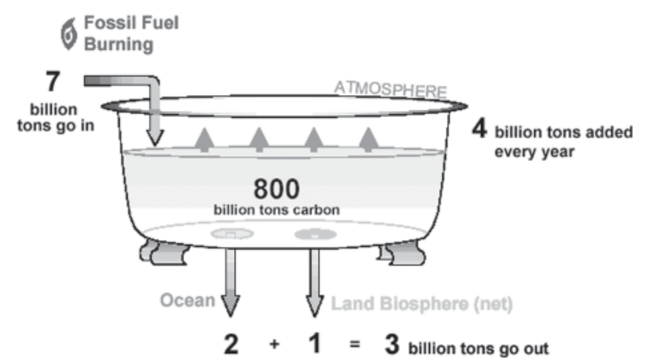


Figure 2

Out of the three units I'm going to pick the "tons of carbon" measurement. Seven billion tons of carbon every year are coming out of the ground. Approximately the same amount of carbon is going into the atmosphere, because not long after it's taken out of the ground, typically months, it will get burned. It'll be carbon dioxide. Not every bit of it is burned, but most of it is.

Carbon Removal Mechanisms

The atmosphere does not grow by seven billion tons of carbon each year, but by something less. That's because there are two removal mechanisms: drains in the bathtub. One is at the surface of the ocean. If there's extra carbon dioxide in the atmosphere, some of it dissolves in the ocean. About 2 billion tons out of the seven get removed that way. There are impacts on the ocean when this happens.

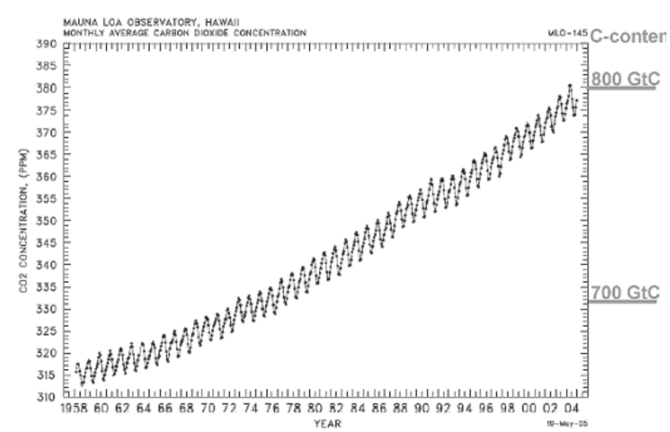
The size of the other removal mechanism is found, in fact, by subtraction. It's hard to measure, no one can model it terribly well. On average there's a net movement of carbon dioxide into plants, and into forests. In spite of deforestation, which affects the "land" arrow and by itself would point *up*, bringing roughly 1 or 2 billion tons of carbon into the atmosphere each year, the net exchange between the biosphere and the atmosphere in these units is one unit going *out* of the atmosphere, a land arrow that goes down. So that's the world we live in.

Climate Change History

The politics of all this starts in 1992 with the Rio Convention on Climate Change, which the United States signed. At that time, you hardly ever heard the word "ocean" in the discussion of the climate change problem. People were thinking about the atmosphere. Today we understand that the surface ocean is being changed by acidification: carbon dioxide goes into the water and makes it acid, which affects coral, for example. We now have a wider understanding of impacts.

We're about to celebrate the 50th anniversary of the measurement program high on the mountain of Mauna Loa, Hawaii, which is one of the two big mountains on the state's "Big Island." When the measurement started, there were fewer than 700 billion tons of carbon in the air, and in the 50 years that this has been going on, it's climbed to 800. It is, of course, still heading up. Figure 3 is the poster child figure for this subject as far as science is concerned.

Mauna Loa CO_2 Data, 1958-2004



Source: Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center http://cdiac.ornl.gov/trends/co2/graphics/mlo145e_thrudc04.pdf

Figure 3

How many of you are seeing this figure for the first time? More than half, so I'll take a minute with it. It's doing two things: the curve is oscillating and it's climbing.

The oscillation presumably was there 500 and 1,000 years ago, but no one measured it. It's the result of an exchange of carbon dioxide between the forests and the atmosphere on an annual basis. When the forests grow, carbon dioxide comes out of the atmosphere into the leaves. When the leaves decay on the forest floor, the carbon dioxide goes back where it came from. At that time, this would have been the whole story. The oscillation would have been centered around 280 parts per million or 600 million tons, and it wouldn't have been rising.

The climb is because we're burning fossil fuels and to a lesser extent deforesting. The climb would be twice as steep but for those two sinks, which are making it climb at the rate that is seen here.

This concludes Carbon Cycle Science 101.

Climate Change Impacts

Then we have the question of impacts. I'm going to use this one figure (Figure 4) to discuss impacts, because I want to move along enough not to take four hours with this presentation.

Sea Level Rise

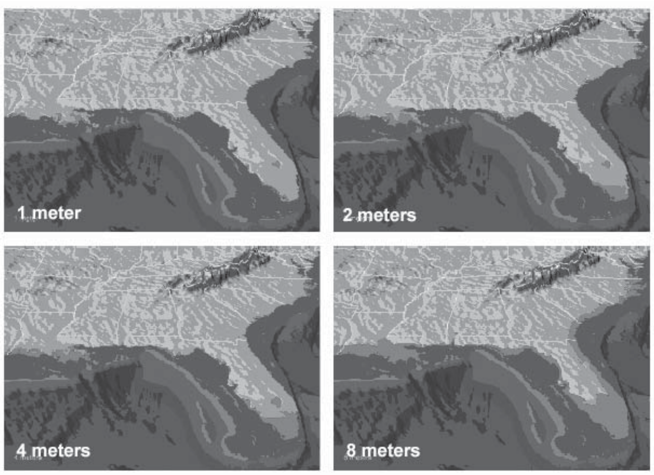


Figure 4

You have here the consequences of sea level rise for the Gulf of Mexico and Florida. The figure reminds you that Florida is very flat. Half of it disappears if sea level is only eight meters higher than it is right now. Will it get eight meters higher? The answer used to be, "We don't have to worry about that for a long time." In the last couple of years, it's, "Well, maybe we do have to worry about that, even now."

There are two ice masses on the planet that are secure for the moment. One is the glaciers of Greenland and the other is what's called the West Antarctic Ice Sheet (it's a piece of Antarctica that points up to Latin America, jutting out toward Argentina and Chile). Each of those, if it were to melt, would be worth about six to eight meters of sea level. You just take the mass of ice, spread it over the surface of the ocean, which is two-thirds of the surface of the planet, and that's how much climb you get.

A question that intrigues me is: "Which of the impacts of Climate Change are the ones that are going to be politically salient?" Is it going to be sea level rise—with a lot of uncertainty about whether it's something we have to be concerned about? Suppose we were told that there is a 10% chance that sea level will rise by 10 meters over the next 1,000 years if we do not address climate change, and that only in 100 years will we know whether this is the track we're on? Would that be enough to engender political action?

Or, considering hurricanes instead of sea level rise (both affecting the same territory, southern Louisiana), will salience adhere to the impacts of rare events becoming more frequent? If a bell curve describes the occurrence of intense storms, droughts, very hot days, and other unwanted environmental phenomena, and climate change simply shifts these bell curves to the right, enriching the upper tail, then there's a bigger chance for extreme events than a focus on average values would suggest. Is that what's going to drive people to action?

In both cases, we can think of our response to climate change as buying insurance. My colleague, [Stephen] Pacala, calls these "the monsters behind the door." There are a bunch of monsters. As we learn more, we find out about more monsters.

Every once in a while, we discover that a monster is not as fearful as we thought it was. There was a lot of concern about the shutting down of the Gulf Stream five years ago, and that was a monster. This outcome may not be as likely as people thought it was. Not everything is getting scarier. But a lot of new knowledge reveals more ways by which our adding carbon dioxide to a complex climate system brings problems for us. Yes, for other species too, but clearly, primarily, for us.

The head of NASA said something very provocative a few weeks ago. He asked why we are privileging the climate of the present time. Why are we going to put all this effort into limiting how much it changes? Someone who spends much of his time thinking about life on Mars might indeed need help with this question. But most of the rest of us can answer: We privilege today's climate because it's the one we've adapted to.

Coming out of the last ice age, suppose sea level had risen above where it is today. Because more glacier melting had occurred, we would have set up our cities in different places; we would have set up our agriculture in different places. We've gotten very locked into this particular way of using the planet. We can move our cities and agriculture, but it's very costly to do so. So, in some sense, in deciding how to deal with climate change we're trading one dislocation against another: the dislocation of adapting to impacts like rising sea level against the dislocation of changing our energy system.

When I talk so anthropocentrically, I am diminishing the impact of irreversible changes on other species, like polar bears. Somehow, we need to make these impacts part of our thinking too.

I'll tell you one last thing about sea level, which I find intriguing: The difference in sea level between its minimum during an ice age and its maximum during an inter-glacial is about 100 meters. The planet's land shape during the last ice age was quite different from today's, with not only the Bering Strait exposed, but also many other land masses.

The last time the Earth came out of an ice age before this time was 120,000 years ago. In fact, the Earth came further out of an ice age that time than this time. More ice melted, and sea level was higher than today by about six meters. So, is our global warming bringing us closer to the world of the last inter-glacial? This is a world where the southeastern U.S. resembles the bottom right panel of the picture (Figure 4).

It's very intriguing; we're learning all this as we go. Discoveries of what the last ice age was like and what coming out of the previous ice age was like (the last relatively warm period) are going to keep coming over the next few years, because many scientists are working on this. We're getting more and more messages that explain the human condition.

Emissions

Steve Pacala and I tried to make sense of what all this had to do with energy and policy. We focused on that 7 billion tons of carbon pulled out of the ground each year today and said, "Let's learn a little more about it." The first thing you can do is look back in the past (Figure 5). We see that 50 years ago the global emissions rate was less than one-third of what it is today.

Earlier today Judge Stein and I were looking at a black-and-white photograph of a scene 50 years ago on the very street in Albany where the hotel is located where I stayed last night, State Street. There were trolleys and some bicycles and lots of cars and older buildings. Albany didn't look in such a bad shape. At that time, the world was using one-third as much carbon (about half as much in the U.S.) compared to today.

Past Emissions

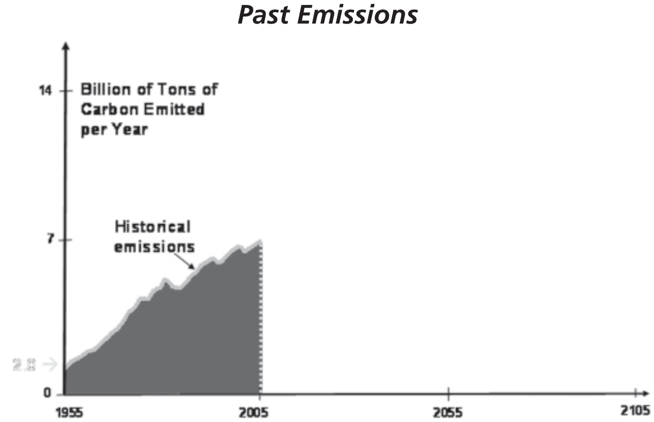


Figure 5

Look at Figure 5. All that blank space at the right side of this picture is intended to provoke two questions. The first question is, "If we don't care about carbon for the next 50 years, what will emissions be?" If we buy Senator Inhofe's view that climate change is a hoax being perpetrated on the American people, it's time to come to our senses: what will be the emissions? There are thousands of papers answering that question, done by a group of people who generally go under the name of econometricians. They use the past as a guide to the future, try to develop what the Gross National Product rate of increase will be, how much technology will come in, and they come up with lots and lots of answers, with a big band of answers.

The other question is, "If we really care about the climate problem and work very hard, what should our goal be for 50 years from now?" Another thousand papers exist with the discussion of that topic.

Because so many papers produced so much noise and so little signal for those of us who are onlookers, Pacala and I asked, "Can't we cut through this?" And we drew this picture (Figure 6). This picture says that about double the carbon extraction rate, 14 billion tons of carbon a year, 50 years from now, is where we're heading if we ignore climate change. Of course, you can make cases for higher or lower numbers, but we needed to make a single choice. We tried to be in the middle of what is out there. The picture also says that if we could keep global carbon emissions to today's level for 50 years, we should be real pleased. We should be proud of ourselves.

The Stabilization Triangle

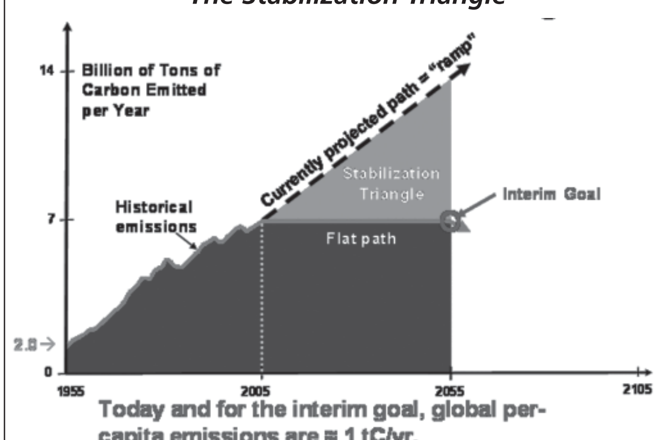


Figure 6

I circled one point on Figure 6, calling it our "interim goal": 50 years from now, the same global carbon dioxide emissions as today. Many of you in this room are going to be around in 2055. Please have a party, and remember us, if the rate really is as little as seven billion tons of carbon per year.

Wedges

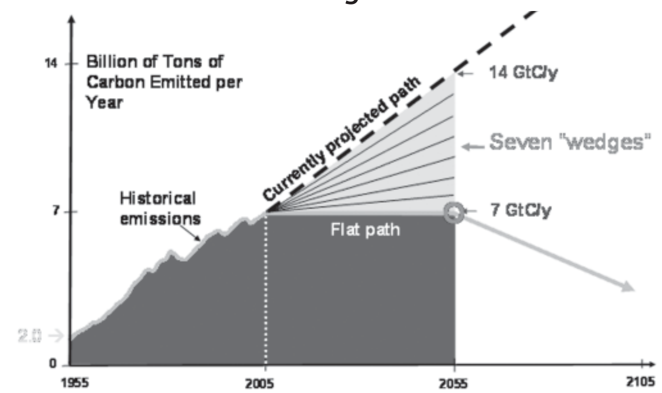


Figure 7

To illuminate that rate in an interesting way, there are about seven billion people on the planet. So our share as individuals is a ton of carbon a year, taking it out of the ground, putting it in the atmosphere. I'm going to repeat that number a few more times and show you how big it is in terms of other things.

I am optimistic that we can meet this interim goal for three reasons. One is that we have a terribly energy-inefficient energy system. At this point in talks, I usually look up at the ceiling in the room I'm in, and, as I do right now, I usually find an incandescent bulb up there. This room is not the most overlit room I've talked in, by a long shot.

The second reason for my optimism is that so much of what will be the world's capital stock in 50 years is not yet built. Sure, some of what we now have, as that photograph in the hotel hallway suggests, will be around in fifty years. But globally, quite a lot is still to be built.

And the third reason for optimism is we haven't yet had a price on carbon. More accurately, we're just beginning to have a price on carbon in a few markets, like the European Trading System. These are the three reasons why I find it possible to imagine achieving all of the savings in the stabilization triangle in Figure 6.

Most of the criticism of Figure 6 in the last three years (a figure that has become something of an iconic figure) asserts that it underestimates the job ahead. The rising arrow isn't rising steeply enough to capture what "Business as Usual" will bring, and the flat line is too timid a course of action to avoid climate change. Keep those criticisms in mind, because to the extent that these criticisms are valid, addressing climate change adequately means doing even more of what we'll be talking about.

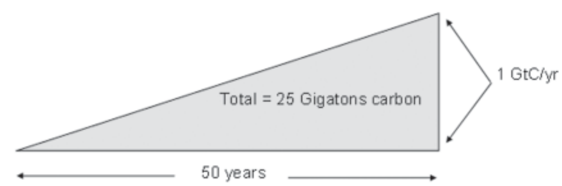
Some of you know the language of two degrees and three degrees as another way of talking about goals. These are proposed values for targets expressed in terms of the maximum rise in the average surface temperature of the planet, compared to the pre-industrial time (in Celsius degrees). We're one degree Fahrenheit (0.6ºC) above the pre-industrial temperature already. Figure 6 can be restated in this language. We're on track for a 3ºC (5.4ºF) temperature rise if we follow the flat path, and for perhaps a 5ºC (9ºF) rise if we follow the rising path. Many Europeans argue today that 3ºC is too much, and that we should aim for 2ºC (3.6ºF). To do so requires roughly cutting the global emissions rate by half in 50 years, a much tougher job than keeping it constant.

The Wedge Model

We did one other thing, Pacala and I. We divided the stabilization triangle into seven equal pieces and named these pieces "wedges," creating a unit of discussion for the subject (Figure 7). A wedge is a campaign or a strategy that leads to one billion tons of carbon per year not being emitted on the planet 50 years from now. It could be a campaign of various kinds, and so you can compare campaigns.

What Is a "Wedge"?

A "wedge" is a strategy to reduce carbon emissions that grows in 50 years from zero to 1.0 GtC/yr. The strategy has already been commercialized at scale somewhere.



Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at $100/tC.

A "solution" to the CO_2 problem should provide at least one wedge.

Figure 8

Our wedge is a triangle (Figure 8). You can verify that it results in 25 billion tons of carbon not added to the atmosphere because of some campaign. I want to call your attention to the price of carbon on this figure, $100 a ton of carbon (about $30/ton CO_2). This is, in my view, the approximate price one ought to have in mind for dealing with climate change. It's not cheap; I'll say more a little later about how expensive it is. This price makes a wedge a $2.5 trillion enterprise. That's a lot of jobs around the world.

So, now we go on a hunt for wedges. First, let's find out where the seven billion tons of carbon are coming from right now. Take Figure 9 as a starting point. The three-by-three set of skyscrapers shows how emissions are split between gas, oil and coal. These are the three forms of carbon that come out of the earth. The figure also shows the split between power, mobile applications, and stationary applications that are not in the form of electricity but use fuels directly.

The two tallest skyscrapers are about equally high, and between them they add up to half of the total, which

CO_2 Emissions by Sector and Fuel

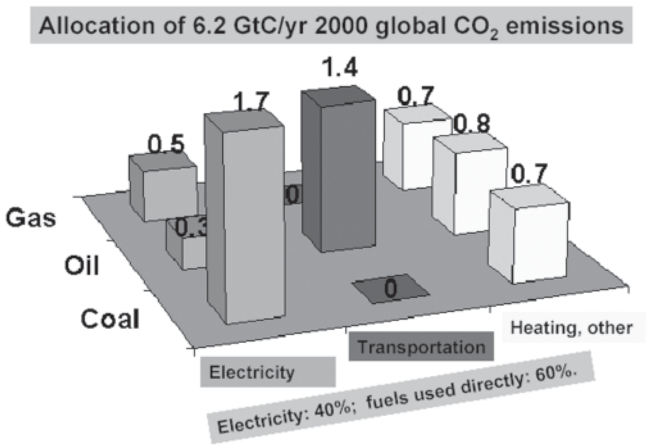


Figure 9

was six billion tons of carbon in 2000. It was seven when Pacala and I wrote the paper. It's around eight right now. When we move past this figure, we'll stick to seven. We're going to change seven to eight with appropriate fanfare sometime soon.

The two tallest ones are coal-to-power and oil-to-transport, no surprise. At the right, you find natural gas going to buildings, which is part of the discussion you're embarking upon today; also oil heat going to buildings, which, I suppose, could escape your process. Since these two compete fiercely, however, you will not really be able to forget oil heat.

If you just take the electricity column, it's 40% of the emissions globally. It's also 40% of the emissions in the U.S.

If you just take the carbon emissions from power, and compare them to the carbon emissions in New York State from everything, does anyone in this room know the percent? It is about 25%.[2] That's because you have a more decarbonized power system than the country as a whole.

We seek broad categories for sorting out the wedge strategies (Figure 10). Energy efficiency is at twelve

Fill the Stabilization Triangle with Seven Wedges

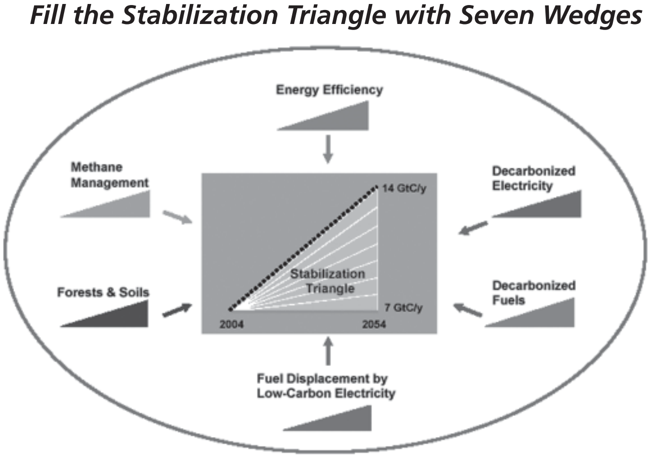
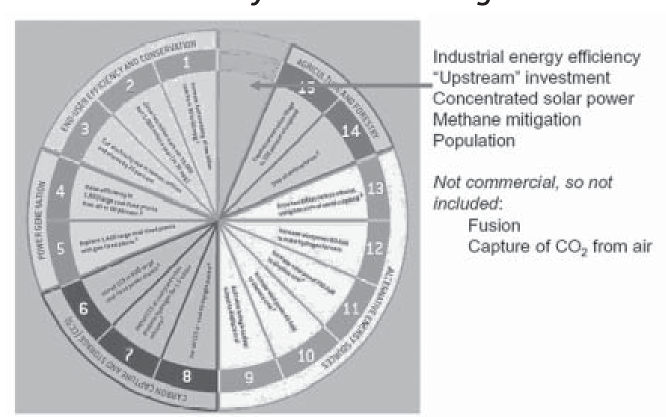


Figure 10

o'clock, because that's where I think it belongs, right at the top. We can decarbonize the electricity system; we can decarbonize the direct use of fuels. At two o'clock and four o'clock, we recognize that both power use and fuel use can be decarbonized, and because of the 40% figure above, neither can be ignored. At six o'clock, we acknowledge that it's harder to decarbonize the use of fuels than to decarbonize electricity. At least that's our current wisdom. So if there's a price on carbon and a tilt in the economy away from emitting carbon, there'll be a shift toward electricity and away from direct fossil applications. An example is the plug-in hybrid car, where much of the energy for driving is coming by way of a battery that is charged from a grid. Another example is the electric heat pump for space heating, which is a very important energy application.

Forests and soils, where we deliberately add to the planet's biomass (and therefore to the carbon in the biomass), e.g., by planting trees, are at eight o'clock. And methane management is at ten o'clock, reminding us that carbon dioxide is not the whole story, that there are other important greenhouse gases. They are less well-understood. They're harder to address. For example, if we want to save methane emissions in New York, I'm not sure I know exactly where to start. Consider the methane issue evidence of the slow pace of science—frankly, an under-attended problem.

15 Ways to Make a Wedge



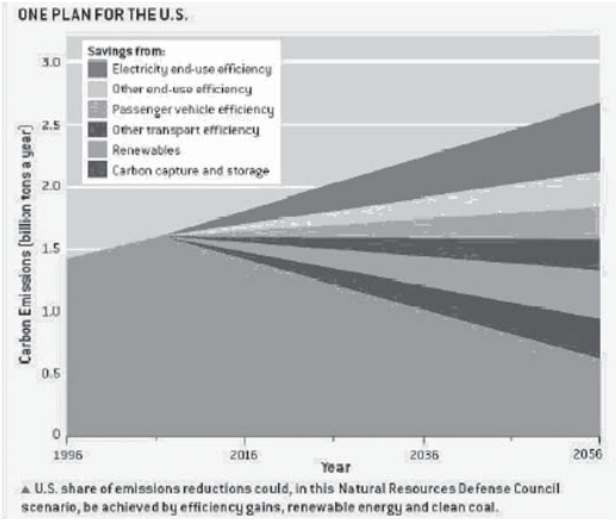
Source: Socolow and Pacala, *Scientific American*, September 2006, p.54

Figure 11

Pacala and I wrote two papers, in *Science* in 2004[3] and in *Scientific American* in 2006.[4] Both have the same list of wedges (Figure 11). I want to identify here a few things that weren't on the list. People say, "Well, here's one not on your list, it must not be important." Read our papers. We said that there are wedges not on our list that are important.

Industrial energy efficiency didn't happen to be on our list. We put in buildings efficiency and vehicle efficiency, but not industrial efficiency, which of course is important. But as all of you know, industrial efficiency

U.S. Wedges



Source: Lashof and Hawkins, NRDC, *in* Socolow and Pacala, *Scientific American*, September 2006, p. 57

Figure 12

is more easily internalized by the decision makers, who will pay more attention to any carbon price that comes in. Carbon efficiency emerges naturally for many of the businesses, especially for those for which carbon or energy is a significant fraction of the total cost. When it isn't, the industry becomes more like a building.

"Upstream" investments are the oil and gas and coal industries' own emissions of carbon as they develop the product for you. We left out concentrated solar power ("CSP") while listing wind and photovoltaics. CSP is a very interesting application where you have troughs in the desert producing high temperature heat to run engines. Also missing are methane (mentioned a moment ago) and population.

It has become unfashionable to link population with environment. This happened in the same period when this whole agenda that we're here to talk about became unfashionable. My shorthand, I hope this is allowed in a room like this, is that Reagan shot the messenger, in 1980 or so. And from then on, environmental problems became less important. The de-linking of population is a part of this story.

I gave a "Millennium Lecture" at Princeton at Alumni Week, only a month ago, to the members of the class of 2000 who returned for reunions. So, they are 28, 29 years old, and there are a couple hundred of them in the room. I said to them, "The most important consumption decision you are going to make is how many children you're going to have." Whoops. Okay.

They said, "Really?"

"Yes."

Fortunately, the past few decades have displayed a very important negative feedback: if we get richer, we want fewer children. Is that feedback robust, or could it get undone? And does this question have anything to do with the task you've set yourselves? I'm not sure.

"The Wedge Model is the iPod of climate change. You fill it with your favorite things." That's a quote from David Hawkins, who works at the Natural Resources Defense Council, and who, with his colleague, Dan Lashof, also made Figure 12. Figure 12 shows U.S. wedges in a world consistent with the Princeton global wedges. Figure 12, which is in Al Gore's movie, shows the U.S. part of that global story and tells us how Hawkins and Lashof would fill their iPod. There is no nuclear power, because NRDC doesn't like nuclear power; but there are four efficiency wedges, one renewables wedge, and one carbon capture and storage wedge in their particular analytical product.

The view of the U.S. in Figure 12 is meant to match a world in which the global emissions are held constant. In such a world, U.S. emissions have to come down and New York emissions have to come down. New York's emissions are about 4% of U.S. emissions.

To complete this general introduction to wedges, I wish to emphasize that every wedge strategy can be implemented well or poorly. These are not miracles. In fact, they're dangerous. For example, nuclear power can be done well, but we're nowhere near doing it well. We certainly don't want to trade climate change for nuclear war.

Conservation can lead to too much regimentation. That, I know, will be on your minds. How much can you intrude on the way people use energy indirectly and directly? I don't know where the right place is to insert it, but I can't resist: You made a major decision in this city two days ago, which is dreadful. It had to do with regimentation and had to do with efficiency and had to do with the way in which we're going to put carbon into the atmosphere and how many years it's going to take to start reducing our national emissions. I'm referring to what happened to the proposal to have congestion charges in New York City. Walking away from this proposal had something to do with avoiding regimentation. Consider the outcome a small taste of what might be coming forward.

Another example of doing wedges badly is not paying attention to the competing uses of land affecting renewables. Still another is "clean" coal. The phrase "clean coal" is widely used by the energy crowd, of which I am part, typically, to mean that you're burning it well, with minimal emissions, including emissions of carbon dioxide. We often forget to insist that the word "clean" should only be used if coal is handled cleanly upstream, too: mining, land reclamation, worker safety all count.

You must assume that whatever you'd like to do as a solution to climate change could be done badly. How will it get screwed up? Ask that question at the front end. You will, of course.

Turning to specific wedges, I'm going to discuss two classes of wedges. I'll go through the first class slowly, because it's about efficiency, the topic of this exercise. I'll go through the second one more quickly; it's about clean coal. These two are, I think, the most urgent ones for the next decade or so.

Efficiency Wedges

We are talking about the consumption of the people on the planet who already have some means, the consumers, the members of post-industrial society. They have appliances in the homes and the vehicles by which they move around dominate the scene. The importance of their consumption in global terms is relatively new, as you saw in earlier figures.

Globally, 60% of oil is used in vehicles and 60% of electricity is used in buildings. In the U.S., 70% of electricity is used in buildings. In New York State in 2006, the fraction was 85%! 150 billion kilowatt hours of electricity were consumed, 52% in commercial buildings and 33% in residences.

The carbon dioxide mitigation challenge is a challenge to both energy supply systems and energy use systems, but for now we'll talk about the use systems.

Here's a carbon number: If your car gets 30 miles a gallon and goes 10,000 miles a year, you're going to put a ton of carbon into the atmosphere. That was your quota as a global citizen, if you remember, for all of your carbon. That one part of your footprint is the global average. Some of you are driving 60 miles a gallon cars 10,000 miles a year, and some of you are driving a 30 mpg car 5,000 miles a year. If you're doing one of those, you're putting half a ton of carbon in the atmosphere.

The first wedge calculation I'm going to show you concerns auto carbon dioxide emissions (Figure 13). The auto industry believes there will be 2 billion vehicles on the planet in 2057, about three times what we have right now. If they are the reference vehicles that I just referred to, 2 billion tons of carbon will go into the atmosphere. If instead, by deliberate policy driven by climate concerns, they are 60 miles per gallon vehicles on average, we'll have a wedge from energy efficiency in vehicles. If we have restructured our cities and commute less and if we are using video-conferencing and drive less on the job, we might actually have a wedge in a different way, 30 miles per gallon cars with 5,000 miles of driving each. Or we could have done both, and we would have a wedge and a half.

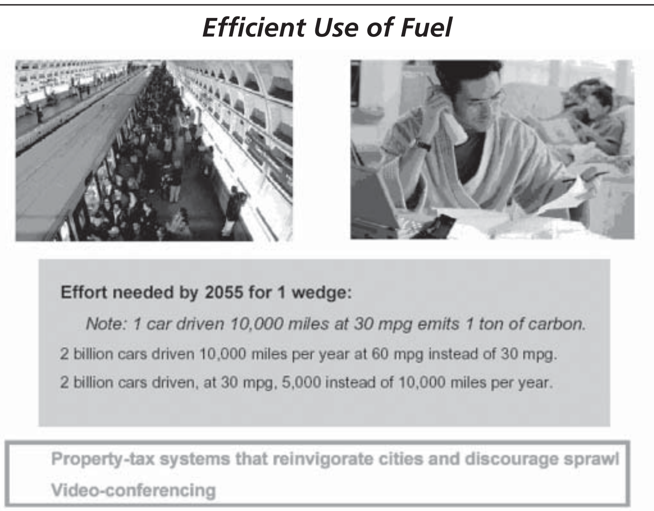


Figure 13

This is not a meeting about transportation. Some of you ought to be (and I'm sure you are) asking yourselves, "How are we going to deal with that other part of the carbon problem in New York State, the carbon coming out of the tailpipes of vehicles?" I hope some groups of people are putting that onto Governor Spitzer's agenda. We are driving more and more in the U.S. We're also not improving the vehicle efficiency.

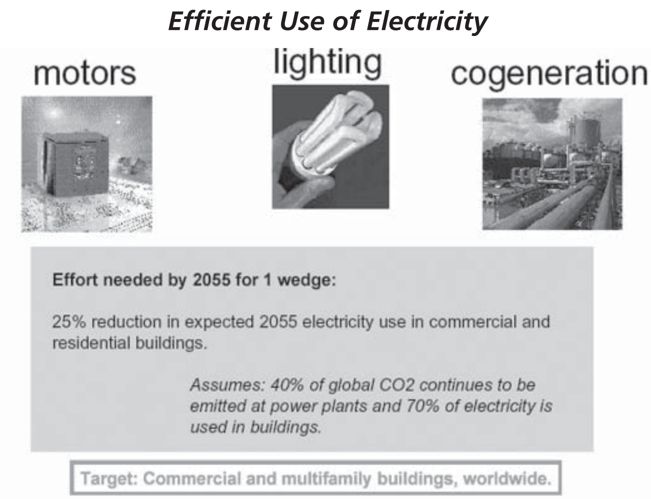


Figure 14

More to the point of your exercise is efficiency in electricity use (Figure 14). If 40% of carbon dioxide will continue coming from power plants, and 70% of that power will be used in buildings, and 14 billion tons of carbon is our baseline, then cutting a quarter out of electricity use in buildings will be a wedge. Cutting a half out would be two wedges. Wedges are hard to find. These are promising and exciting wedges. Obviously if we're decarbonizing the power system at the same time, we're doing better still. And if we're recarbonizing, moving to coal, these are even more important wedges.

I've got three images in Figure 14. One is the variable speed drive motor. An awful lot of electricity is consumed in motors, and motors can be made a lot more efficient. Another is the compact fluorescent bulb that isn't in the ceiling straight over my head. The third is a cogeneration plant, which is using both electricity and the heat generated in producing it. The Public Utility Regulatory Policies Act of 1978 (PURPA) enabled cogeneration. It was a conceptual breakthrough. It forced utilities to allow non-utility generators to put their electricity on the grid. It and CAFE were perhaps the most important carbon related initiatives.

Which new conceptual breakthroughs will you produce, your generation's equivalent of PURPA and CAFE, that the energy policy community will talk about with admiration twenty years from now?

Five Ways to Cut 1 Ton C/yr. by Half

	1 ton carbon/yr	Cut in half	How?
a) Drive	10,000 mi, 30 mpg	60 mpg	Lighter, less power(?)
b) Drive	10,000 mi, 30 mpg	5,000 miles	Live closer to work
c) Fly	10,000 miles	5,000 miles	Video-conference
d) Heat home	Nat. gas, av. house, av. climate	Insulate, double-pane windows, fewer leaks, condensing furnace,	
e) Lights	300 kWh/month when all-coal power (600 kWh/month, NJ)	All-coal power: add CCS* at 60% of the plants, or permanently replace twenty 60W incandescent bulbs, lit 6 hrs/day, with compact fluorescents.	

*CCS = CO_2 capture and sequestration

Figure 15

To be concrete about energy efficiency, consider Figure 15. I list activities that emit a ton of carbon per year and how to cut them in half. The first two are from our already discussed reference car, which we can drive less or exchange for a car with better fuel efficiency.

The third is about air travel. A mile flying in a commercial aircraft has about the same associated carbon dioxide emissions as a mile of driving alone in our reference car. Many of us in this room have to face the fact that our footprint is dominated by plane travel. Only a small fraction of the people on this planet have carbon footprints dominated by air travel, but it's an awfully common situation among analysts who work on energy efficiency.

As for the fourth item, residential heating, I've worked out the CO_2 emissions that accompany the heating of my own home in Princeton, which is not a McMansion. I heat with natural gas, and the carbon emissions from that heating are just about a ton of carbon a year. I split that with my wife, so that's a half a ton of carbon for me. It could be a lot easier to make this calculation, and your group could address this. My gas bill is in therms. Few people have a clue how to go from therms to tons of carbon. (Answer: Burn about 700 therms of natural gas and a ton of carbon will go into the atmosphere.) The gas bill could do this for us.

We energy analysts were talking in the 70s endlessly with the utilities about what goes on the bill statement. I feel like I'm Rip Van Winkle, you know? Those histograms on your bills today with bars on them showing gas consumption are the result of the 70s work. They don't have anything directly to do with carbon, because carbon wasn't what we were specifically interested in, but the arguments and outcomes are all transferable from energy to carbon. Carbon histograms could be constructed by changing a couple of keystrokes. You could tell customers what the carbon footprint was in their home: giving them annual numbers, comparing these numbers with past values, comparing them to a reference group, and doing whatever else you wanted to do. All these ideas were discussed a great deal in the 70s literature.

For electricity consumption, the final item in Figure 15, the story is slightly more complicated than with gas. We need extra information from the electric utilities. With gas, you can go from therms to carbon without further information, and so you can work out your emissions yourself if you want to. Your local newspaper might tell you how to do it. But for electricity calculations, you need another number: the carbon intensity of your particular utility for some particular time period. What exactly were the energy sources that produced the electricity you happened to buy that month? That's known, but it's not known past the utility level today.

If I used 300 kilowatt hours a month (which is about a third of my own actual electric bill) my carbon footprint would be a ton of carbon a year—provided I used coal-based electricity exclusively. But New Jersey is about half as carbon intensive as that, so 300 kilowatt hours would be associated with half a ton of carbon. In New York State, you're going to get quite different answers in different parts of the state. The carbon footprint for electric power, which is key to what your meeting is about, is geographically dependent within the state because the key conversion factor depends on how much of your power comes as hydropower from Canada, or nuclear power from your own plants, or coal power produced in Pennsylvania.

You have a job ahead of you to translate this to the public. But when you do, you'll create a lot of understanding you'll be able to build upon. At least I think so. You just might impact China when you're all done. Don't forget that. The world is going to watch what you do. You're actually early movers.

China Appliance Standards

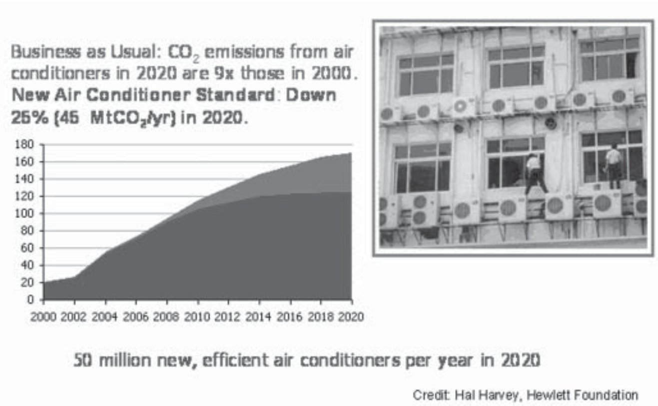


Figure 16

Here is a marvelous picture. I think these guys are cleaning windows and they're not even wearing safety belts (Figure 16). But they're standing on the room-by-room air conditioners that are sprouting like mushrooms all over China. The figure also shows two projections of the carbon dioxide emissions from China's air conditioners, with and without an advanced efficiency standard in place. With the standard, China will install 50 million new efficient air conditioners a year in 2020. The figure says that the efficiency policy, if enforced, will produce that upper wedge of savings, which has grown to 45 million tons of carbon dioxide per year (12 million tons of carbon a year) in 2020. Is it conceivable that U.S. labor could make these air conditioners, or parts of them?

How does New York's air conditioner standard compare with the Chinese standard? Does New York State have a tougher one than the U.S. federal standard? Is it allowed to have a tougher standard? I look forward to having your group broadcast this information. The work begun in the 1970s on appliance efficiency standards surely did improve the air conditioner, but if I'm not mistaken, progress stopped at some point, and now you're going to help make progress resume.

To Achieve Efficiency

Measure, measure, measure (institutionalize skepticism: trust, but verify)

For existing buildings, go building by building

For new buildings, anticipate the undoing of good intentions (e.g., interior design and the aesthetics of daytime mood lighting)

Use policy:
- Performance standards (appliance efficiency, interior temperature, light levels)
- Bounty for old stuff (cars, appliances)
- Time-of-day pricing and congestion charges(!)
- Lifeline rates

Utility economics: decouple profits from sales

Anticipate increases in kWh consumption via shifts from fuel to power (hybrid vehicle, heat pump)

Figure 17

I put this figure together for you (Figure 17). What did we collectively learn in the 70s and 80s about efficiency?

Measure, measure, measure. Maybe you wouldn't expect that as number one. What does it mean? Don't give prizes for designs of buildings before they're built, for example. There is such a large shortfall unless you're watching and can see the outcomes. President Reagan said, "Trust, but verify." That principle, which couldn't have better credentials, sums up the most important lesson we learned about efficiency the first time around.

For existing buildings, go building by building. They're all different. In the 1970s and 80s, trained workers were going building by building, sometimes working for the gas and electric utilities, which had put these costs in their rate base. My own research group at Princeton developed diagnostic tools using an infrared camera and equipment to pressurize a building, so that trained personnel could understand energy efficiency opportunities, which were numerous and were usually related to deficiencies in building design and construction.

For new buildings, anticipate the undoing of good intentions. My own group monitored nominally low-energy buildings that were designed so that daylight would penetrate deep into the interior. The designer imagined that the perimeter office would be occupied by an executive who would be perfectly happy to have a glass interior wall. But, alas, he wasn't, or she wasn't. The executive valued privacy and used a curtain. As a result, daylight did not go to the interior.

Nominally low-energy buildings generally assume low demands on energy for discretionary activities inside. But the interior decorator in one building we studied thought that there should be oil paintings on the walls and that they should be lit by task lighting. All of this happens; all of this happens. So to save energy in buildings, we must get the interior decorators into the electricity efficiency business. So far, they've not been told that saving energy is what their client wants them to do. The same can be said of the lighting specialist, who could find lighting solutions using less energy if asked to do so.

Performance standards. These clearly have great impact. They determine appliance efficiency, interior temperature and light levels. Light levels in schools, for example. I'm telling you 70s stories. We discovered that the lighting standards were captives of the lighting industry, which found ways to justify the need for great amounts of interior light in order to do various tasks. And we, meaning a group of intruders into the worlds of lighting and heating and ventilating, and there were hundreds of us (I just played a minor role) started challenging these arguments. We asked about the evidence that you need the extra light in order to do a particular task. We asked whether there might be a concept called over-lit. Well there *is* a concept called over-lit.

Bounties. Are there any bounty policies in New York? Decades ago, the California authorities were paying people to give up their old, inefficient refrigerators, and would come to your house to pick them up. Some of these inefficient units had been put in the basement when a person bought a new refrigerator; they were often running while hardly being used. California was doing the same thing for old cars.

Time of day pricing and congestion charges. I put that exclamation mark on the night before last, when I read about the impasse regarding congestion charges for New York City.

Lifeline rates. This entry connects the environmental and the environmental justice communities. One of the arguments against efficiency improvements that shouldn't have any weight at all is that these improvements will hurt the poor. This never needs to happen, because one can always implement lifeline rates, where the first block of consumption is less expensive than the next block of consumption. It's a progressive policy idea. Any governing body can do as much of it as it wishes, with a political fight. If the overall result of some policy is that retail electricity or retail gas gets more expensive on the average, there's nothing conceptually difficult about protecting the first block of kilowatt hours or therms from a price increase. The richer consumers then carry a bit more of the total burden. I don't know the extent to which lifeline rates are a feature of present rate structures in New York.

Decouple profits from sales. This is a goal Amory Lovins, in particular, has been articulating for as long as I have been in this game. The regulatory body sets utility revenue rules that create incentives to sell not raw kilowatt hours but the services that power produces. With such an arrangement, an investment in energy efficiency that reduces kilowatt hours sold is still rewarded.

Anticipate increases in kWh consumption via shifts from fuel to power. Strong carbon policy is likely to add kilowatt hours to sales. Say that our country has a goal of reducing carbon dioxide emissions by 15% below levels projected for 2015. As carbon policy starts to kick in, you should anticipate shifts to heat pumps and to hybrid vehicles. You don't want to set electricity production goals that result in fighting these shifts. How are you going to do that? A goal of simply reducing kilowatt hours may not be sufficiently subtle.

Wedges of Energy Supply

Let's discuss energy supply for a few minutes.

In the United States, the electricity sector is becoming more carbon-intensive, which, from a climate change perspective, is not good news. This development reverses a trend of a very long period, 50 years or more, when the nationally averaged carbon emissions per kilowatt-hour produced fell steadily. I'm pretty sure these trends have been true as well for New York State, but it would be good to see a graph of these data to be sure.

The surprise of the last five years has been that natural gas is not going to be the source of choice for incremental electricity in most of the country, but coal is going to be very, very competitive. It's the worst possible news from a climate perspective. Another carbon number you might consider learning is this one: seven hundred 1,000-megawatt power plants (big ones), running on coal, will put a billion tons of carbon into the atmosphere a year. So not building those plants is a wedge.

The International Energy Agency said in 2005 that we're going to put the equivalent of 1,400 times 1,000 megawatts of new coal power plant capacity into place globally, a lot of that in China, but some of it here, by 2030. So we have a tremendous challenge to build a different plant than the one we're heading for. And because of the length of time that coal plants hang around, we have very little time to procrastinate.

Emission Commitments from Capital Investments

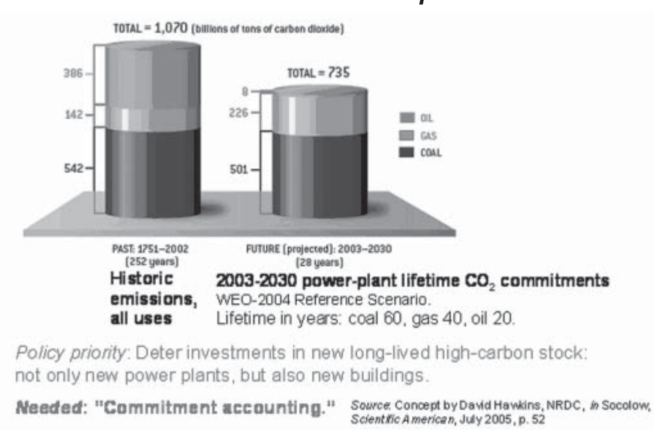


Figure 18

To understand the carbon dioxide emission commitments embedded in new coal plants, consider Figure 18. Consider the bottom barrels only. The left bottom barrel is all the coal we've ever pulled out of the ground until now, and the right-hand barrel is all the coal that will be pulled out of the ground to fuel those 1,400 coal plants over their lifetimes. The two barrels are about the same size. So that's how much carbon is at stake.

Maybe this is a place where those involved in the new New York State initiative could innovate. Today, carbon dioxide analysts do only one-column bookkeeping, and we could be doing two-column bookkeeping. By one-column bookkeeping, I mean that analysts work out (and in some instances are required to report) only the carbon being emitted in a given year—for example, in New York State, in some municipality, or in some home. No one has the task of measuring and reporting the amount of future carbon emissions committed by the investments made by the same geographical entity in the same year—different and complementary data. Private industry does such double bookkeeping all the time. Firms routinely estimate future obligations when they build something. We don't do that in the public sector. But New York State could start.

An additional assumption is required, before one can make estimates of future committed emissions—namely, how long is the thing going to be around? You'd have to justify your answer. A coal plant, I argue in Figure 18, is going to be around 60 years. Somebody might want to say 45 years, or lower the height of the right-hand lower barrel. To institutionalize "commitment accounting," a government would have to debate these additional assumptions and then embed its choices in the reporting methodology.

It could be a perfect role for New York State to report how much future carbon emission is implicit in the construction going on in the State. Items to be included are the lifetime fuel consumption of any new home that is sold and the lifetime power and fuel use in any building under construction. Would it be charged at groundbreaking? At time of occupancy?

The reason that commitment accounting is important takes us back to our view of the atmosphere as a bathtub: from a long-term climate impact, it doesn't matter if carbon dioxide enters the atmosphere next year or five years from now. Carbon is around for so long that we really can sum over future years and find out something meaningful. I recommend that you think about an expansion of how governments do carbon accounting as one of the outcomes of your work.

U.S. Power Plants by Fuel Type

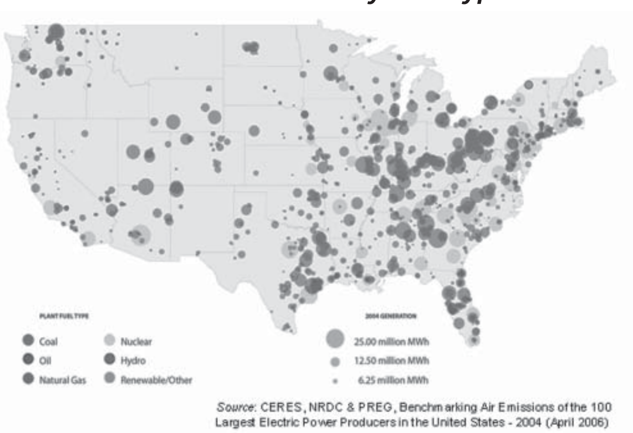


Figure 19

I want to show you this wonderful graph, which I found recently (Figure 19). It shows the conditions right now for electric power plants. One issue is to distinguish between what you produce inside your state, what you import, and what you export. In New Jersey, my home state, there's a complex issue relating carbon accounting and imports: New Jersey gets about half of its electricity from across the border in Pennsylvania and other states to the west.

You're more self-contained in New York State: you imported only 12% of your electricity in 2006. But you are still going to need to be careful about where you draw the system boundary for your bookkeeping. When you talk about carbon emissions in New York, you ought to include the emissions produced in other states that accompany the power you import. Then, your "score" will depend on whether you're importing hydro or nuclear or coal power.

Look at the Appalachian region in Figure 19. It reminds me of the Japanese game of Go. All the darker circles, coal plants, produce an empty region that looks like captured territory. Then the lighter circles, nuclear plants, form a ring around the coal.

U.S. Power Plant Capacity, by Vintage

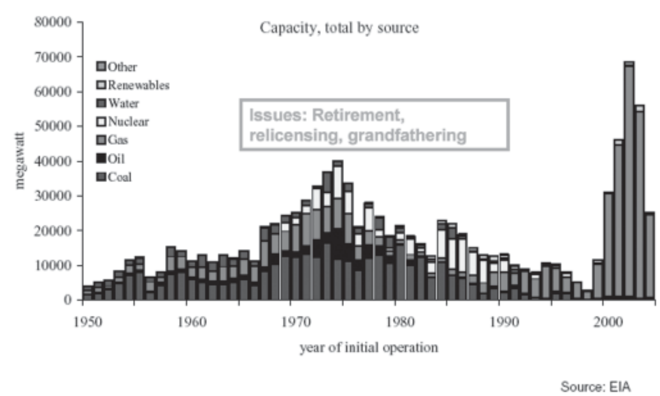


Figure 20

Figure 20 shows when the currently operating U.S. power plants were built. The bottoms of each bar are the coal plants, and the light parts of the bars in the 1970s and 80s are the nuclear plants. We have lots of power plants that are 30 to 40 years old. As a result, industry and government are confronting relicensing, grandfathering, retirement, and "scrap and build." Scrap and build means tear down the current plant, stay at the same site, and build something new and spiffy, a process with considerable virtue from an environmental perspective.

Note the remarkable lemming-like behavior at the far right, which some of you know much more about than I do. We built an extraordinary amount of natural gas power when many investors persuaded themselves that this was a brilliant thing to do, when it may have been for each of them acting alone but was not when many others did the same thing. The price of natural gas went way up, with all this new demand (and for other reasons), with the result that many of the plants on the right are either mothballed or running many fewer hours a year than they were expected to. Several firms went bankrupt. It is sobering how a very few years ago, a large number of investors made a collectively wrong decision.

I just spent very little time on the many alternatives to building coal plants, because I want to have a little time for discussion. Wind power, for example, can replace coal. But you need a huge amount of wind: to replace 700,000 megawatts of coal would require about 2 million megawatts of wind. (The reason the two numbers don't match is because the watt that we're talking about in both cases is a peak watt, and the intermittency of wind is worth about a factor of three when you compare wind to coal.) Wind is growing 30% per year globally. It's growing substantially in the U.S. I don't know whether there are major wind issues in New York State.

Decentralized electricity production is another option. Every roof is a potential energy collector. In your exercise, you're going to have to ask how you're going to count decentralized kilowatt-hours versus centralized kilowatt-hours, confronting "net metering," for example.

Nuclear energy will be on your plate as well. I imagine that your key issues over the next ten years will involve relicensing.

The Future Fossil Fuel Power Plant

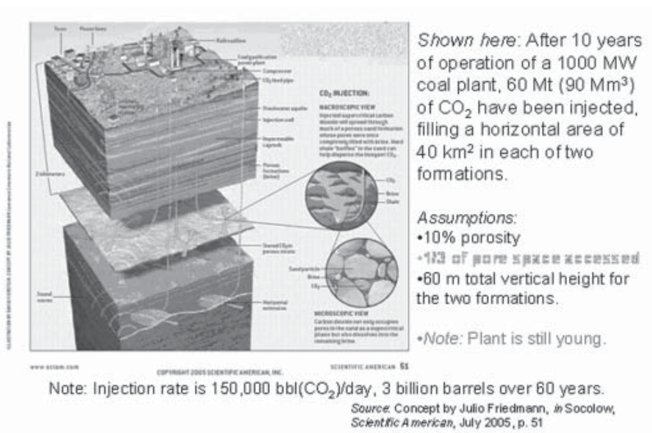


Figure 21

Last of the alternatives to coal-as-we-know-it is a favorite of mine, because I spend a lot of time on it, where we modify coal plants so that they're capturing their own carbon dioxide emissions and putting them underground. This half-a-loaf strategy assumes that we are going to continue to build fossil fuel plants and tries to transform their impact on the environment. Figure 21 is from an article I wrote in the August 2005 *Scientific American*, called *Can We Bury Global Warming?* I tried to imagine a coal plant that was capturing carbon dioxide and putting it below ground and forced myself to get quantitative about the amount of carbon dioxide you would collect and how big a space it would occupy below ground. Probably all of you in this audience have heard of this concept by now, but it is still largely unknown by the general public.

We can't simply shut down the coal system. But we can build a different kind of coal power plant, at some extra costs. One such plant, at Huntley, is being discussed for western New York, where the captured carbon dioxide will be sequestered deep below ground to the south and west of Buffalo. As I understand it, state money will be required to make this path-breaking project happen.

\$100/tC=2¢/kWH Induces CCS. Three Views.

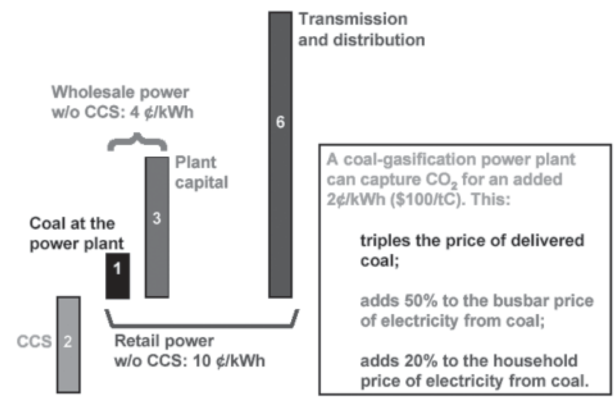


Figure 22

Carbon management is going to increase the price of electricity, and Figure 22 presents three ways of thinking about this increase. Think of the extra cost of carbon capture and storage (CCS) at a power plant as two cents per kilowatt-hour. That extra cost is about the same as the extra cost for the same coal plant if its normal carbon dioxide emissions are charged \$30 a ton of carbon dioxide or \$100 a ton of carbon. (\$30/ton CO_2 is the breakeven price.) The question then, is, compared to what? Compared to the cost of coal, to the wholesale cost of power, or to the retail customer's cost of power?

We'll use ballpark numbers, all in cents per kilowatt-hour. It's about one cent for the coal burned, three cents more for paying off the capital costs for building the plant, and another six cents for the transmission, distribution, and retail handling costs between the power plant and the residential consumer. Those numbers aren't exactly right for any specific situation, but they're conceptually right. So if you're in the coal industry, you're looking at a tripling of the cost of your product, and you could be losing out in your competition with natural gas. If there is a \$30/ton CO_2 carbon tax, it'll triple the cost of your coal delivered to the utility. The utility is looking at a 50% increase in its plant-gate ("busbar") costs. The residential customer is looking at a 20% increase in the costs on the bill. How hard people will fight your carbon policy that leads to a \$30/ton CO_2 emissions price (whether they will tie you up in court, for example) is implicit in the numbers in Figure 22.

To be sure, Figure 22 assumes that the extra carbon dioxide cost gets passed from one transaction to the next without overheads being charged or costs being partially absorbed, something that legislation could assure. Similar legislation governs the pass-through of fuel escalation costs in electricity markets.

Without such legislation, all along the value chain, percent overheads could be charged on top of the whole-sale carbon dioxide emissions price, and two cents per kilowatt-hour on the coal could turn it into seven at your home. You don't want that to happen.

The utilities argue the other way. They want to make sure they can recover the full two cents. The consumer advocate should have the job of making sure the cost of carbon dioxide mitigation is moving through all the transactions right in the middle of the fairway.

Avoid Mitigation Lite

Carbon emission charges in the neighborhood of $30/tCO$_2$ can enable scale-up of most of the wedges, if supplemented with sectoral policy to facilitate transition.

Form of Energy	Equivalent to \$100/tC or \$30/tCO$_2$
Natural gas	$1.50/1000 scf
Crude oil	$12/barrel
Coal	$65/U.S. ton
Gasoline	25¢/gallon (ethanol subsidy: 50¢/gallon)
Electricity from coal	2.2¢/kWh (wind and nuclear subsidies: 1.8 ¢/kWh)
Electricity from natural gas	1.0¢/kWh

$100/tC was the approximate EU trading price for a year ending April 2006, when it fell sharply.

Figure 23

How can we think about $30 a ton of carbon dioxide and the carbon policy that might get us there? (Figure 23) First, it's far more than the emissions costs usually being talked about in Washington today. It is far more than being talked about as a cost in the Regional Greenhouse Gas Initiative (RGGI)—the interstate initiative being designed by northeastern U.S. states today, including yours and mine. And, I think it's the kind of cost we need to expect, and to put into place.

How much is \$30/ton CO_2 in other energy units? It would help if more people could know the answers. Because there's a specific amount of carbon in any ton of fuel or gallon of fuel, these answers are well defined. I've prepared Figure 23 for you to keep and refer to.

Natural gas is measured in the U.S. either in therms or in standard cubic feet. \$30/ton CO_2 is about fifteen cents a therm, or $1.50 a thousand standard cubic feet. Wholesale natural gas prices, at the point where the gas enters our interstate pipeline system, are about four times higher than that today, and at the customer level, maybe ten times higher.

The corresponding price in units familiar to those who work with crude oil is $12 a barrel, about a sixth of the current reference price that we read about in the papers.

Coal prices are usually in tons, and \$30/ton CO_2 is about \$65 per ton of coal, approximately twice what a New York State coal burning utility pays for coal. A \$30/ton CO_2 price on carbon dioxide emissions to the atmosphere has a truly big impact on the competitions between coal and natural gas for electric power and the competition between fuel oil and natural gas for home heating fuel.

Coal, oil, and gas are affected unequally by a price on CO_2 emissions, because the three feedstocks produce different amounts of CO_2 when they deliver the same amount of energy. Natural gas emits only a little more than half as much CO_2 as coal and about two-thirds as much as oil. The underlying reason is a difference in the amount of hydrogen in each fuel, compared to the amount of carbon. Hydrogen burns to water and produces no CO_2. As a result, when more hydrogen is present for the same amount of carbon, more energy is produced for the same amount of CO_2. Natural gas has the highest hydrogen-to-carbon ratio of the three fuels.

By the time the price of \$30/ton CO_2 reaches the consumer, if it's a straight pass through, it's twenty-five cents a gallon of gasoline, a price that isn't likely to have a big effect on driving. It's two cents per kilowatt-hour for a customer whose electricity comes exclusively from coal power plants. It's one cent per kilowatt-hour for a customer whose power comes from natural gas. It's also about one cent per kilowatt-hour for an average New Jersey resident, given the mix of the nuclear, coal, and gas power plants that produce our electricity.

Given the way these numbers work, I think you will agree that it is important to levy the carbon dioxide emissions charge far "upstream," ideally, where the fossil carbon comes out of the ground or across our borders. The further upstream, the higher the percent impact on the price of the product for the same charge. If one places the charge far downstream where gasoline is purchased and electricity bills are paid, the result of the same carbon dioxide emissions charge is likely to be much less carbon dioxide emissions reduction. If there is a carbon dioxide tax, impose it on the fossil fuel producer and importer; if there is a carbon dioxide cap-and-trade system, cap the carbon flows of the same players. I think discussions of carbon dioxide policy design haven't focused enough on this question of who the players are who will be targeted initially by the policy. I can believe that in an ideal market it doesn't matter, but in sticky markets it does.

Do I have this right? If I do, and yet for societal buy-in you want involvement of the downstream consumer (the retail consumer of gasoline and electricity) in carbon policy, you're going to need to supplement price with policy to get carbon dioxide savings. Price is not going to motivate a whole lot on its own. An example of policy is CAFE, the Corporate Average Fuel Economy standard that governs the new-car market.

We will need a ramp to get to $30/ton of CO_2. It seems to be an academic's role to make options vivid, so to be specific, what about a ramp that climbs to $30 per ton of CO_2 in ten years—an increase of $3 per ton of CO_2 every year for ten years. Five years into the policy, the price is $15 per ton of CO_2. The start date might be 2010.

If, instead, we lock in much lower carbon dioxide prices, we set up what I call "Mitigation Lite," and I say avoid "Mitigation Lite." Mitigation Lite has the right words and the wrong numbers. Advocates of Mitigation Lite argue that we can fix the numbers after we've gotten used to the right words. The trouble with this line of reasoning is that the industry negotiators are saying, "We'll take anything you want to throw at us as long as you promise not to change it." Mitigation Lite is a poor option, if regulatory certainty for a decade or more is attached to it.

Can We Do It?

Finally, can we do it? People, *we*, are becoming increasingly determined to lower the risk that we and our children will experience major social dislocation and environmental havoc as a result of rising carbon dioxide in the atmosphere, and we are learning that there are many ways of changing how we live, what we buy, and how we spend our time, that will make a difference.

We are in the midst of a discontinuity. What once seemed too hard has become what simply must be done. Precedents include abolishing child labor, addressing the needs of the disabled, and mitigating air pollution.

What once seemed too hard has become what simply must be done. Thank you.

Endnotes

1. For further reading, see two papers by Steve Pacala and Rob Socolow: 1) *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*, 305 Science 968, 968-972 (2004) (and its Supporting Online Material); 2) *A Plan to Keep Carbon in Check*, Sci. Am., September 2006, at 50-57.
2. *See* New York State Energy Research and Development Authority, Patterns & Trends: New York State Energy Profiles: 1992-2006 (Jan. 2008), *available at* http://www.nyserda.org/publications/Patterns%20&%20Trends%20Final%20-%20web.pdf.
3. S. Pacala & R. Socolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*, 305 Science 968, 968-972 (2004).
4. S. Pacala & R. Socolow, *A Plan to Keep Carbon in Check*, Sci. Am., September 2006, at 50-57.

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