

CHAPTER SEVEN

Our Energy Sector and our Climate Assets*Environmental Capital at Risk*

One of humanity's most precious environmental assets is a global climate that is neither too hot nor too cold, and whose snowfalls and rainfalls are plentiful enough to protect the agriculture they have always nourished. A climate that turned too cold would make much of Europe unlivable. A climate that turned too hot would melt the ice sheets on Greenland and West Antarctica, raise global sea level by more than forty feet, wipe out major urban areas, dislocate tens of millions of people, produce extremes of drought in some areas, storms in others, and potentially trigger catastrophic conflict. No rational person wants the global climate to take a turn for the worse.

Another vital asset is the chemistry of the world's oceans. For shellfish to form their shells, for coral to grow properly, the ocean that is their home must offer a sufficient supply of calcium carbonate. As it happens, rising levels of carbon dioxide in the atmosphere also produce rising levels of dissolved carbon dioxide in the ocean. But matters don't stop there. Carbon dioxide in the ocean produces carbonic acid, and the greater the ocean's supply of carbonic acid, the weaker its store of calcium carbonate. Carbonic acid depletes calcium carbonate. An ocean too rich in carbon dioxide becomes an ocean that's less able to provide the calcium needed by shellfish and coral. A healthy ocean, in other words, is one that's low enough on carbon dioxide that shellfish and coral can obtain the calcium carbonate they need; a very sick ocean is one with too much carbonic acid and no shellfish or coral.

Both of these vital assets, a robust climate and a healthy ocean, are directly affected by the template replication activities of the world's vast energy sector. Our ancestors couldn't have known, when they first invented steam engines to capture the power in coal, when they first invented cars and gasoline to capture the power in oil, that they were adopting templates whose endless replication would place at risk both the global climate and the chemistry of the world's oceans. But so they were. If we are to think large, and think long, and be good stewards, we have to look unflinchingly at where we are, where we're headed, what it means, and how we should respond. These will not be easy lessons to teach ourselves, but they are not beyond us either. In this chapter, and the next two, I will pull out what I regard as the most essential lessons for us to absorb and apply.

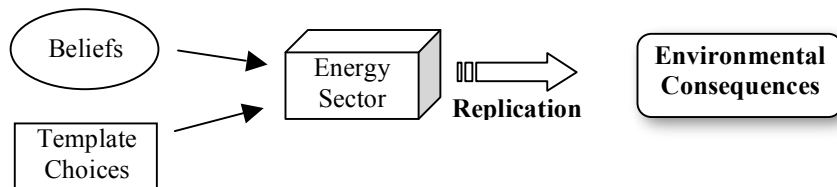
The American economy has an enormous appetite for energy technologies and the power sources that make them go. Roughly ninety percent of our end user energy comes from fossil fuel – 1.1 billion tons of coal, 7.5 billion barrels of oil, 22 trillion cubic feet of natural gas, each year, year after year.¹

And, as a consequence, America's energy sector belches out almost six billion metric tonnes of carbon dioxide per year – very nearly 20 tonnes of carbon dioxide per person per year.

¹ In this book, I use "ton" to refer to an English ton of 2000 pounds. I use "tonne" to refer to a metric tonne, 1000 kilograms, roughly 2200 pounds.

We imagine that our national wealth is somehow synonymous with our capacity to burn through Mother Nature's inheritance at the fastest possible speed, instead of thinking, as we might, that true wealth derives not from the capacity to squander but from the capacity to conserve. Those who know the New Testament might see in the story of The Prodigal Son a cautionary tale that warns us against burning up Nature's fossil fuel heritage at the fastest possible rate. We pride ourselves on having been smart enough to devise all the wondrous technologies that use fossil fuels, but claim, now, that we are not nearly smart enough to invent a new energy regime that spares the Earth from its rising overload of carbon dioxide. It is an interesting conundrum, and will test our resourcefulness as stewards. The tougher the challenge, though, the more competence we gain by addressing it sensibly and resolving it favorably.

In this chapter, I focus on the scope of humanity's carbon dioxide output, and the essential takeaways from science that we must understand if we are to appreciate the consequences of our actions.



In Chapter Eight I turn to issues of belief and how they affect the guidance we give our energy sector. In Chapter Nine I lay out the template redesign challenges to be addressed as we strive to innovate our way out of our current predicament.

Why So Many Scientists Are Alarmed

Let's begin at the beginning. Fossil fuels are the hydrocarbon residuals from the swamp life and marine life that inhabited our planet millions of years ago. As marine creatures died and settled to the bottom of the sea, for millions of years at a stretch, their remains created the hydrocarbon reservoirs that eventually turned into petroleum. As swamp plants died on land, and accumulated over countless generations, their remains created the hydrocarbon reservoirs that geologic time eventually converted into coal.

When a hydrocarbon fuel is burned, be it coal, oil, or natural gas, the stored energy of primeval sunlight is released. Oxygen from the air combines with the carbon of hydrocarbon to release heat and form new molecules of carbon dioxide; oxygen also combines with the hydrogen of hydrocarbon to release heat and form new molecules of water. In a fossil fuel economy, these are the chemical reactions that liberate the energy of stored sunlight and give us the means to run ships and trains and cars and power plants and factories and to warm homes and much else besides.

A Rising Stock of Atmospheric CO₂. For quite a long time, no one knew for sure what happened to the carbon dioxide gas that such combustion releases into the atmosphere. Maybe the oceans soaked up all the new carbon dioxide. Maybe the forests did. Or maybe some of it remained in the atmosphere. No one knew for sure, till in 1958 the world's first carbon dioxide observatory was established, in Hawaii, on Mauna Loa. Ever since then, scientists at Mauna Loa have been

taking hourly measurements of the carbon dioxide concentration in the atmosphere. Other observatories now do the same, elsewhere in the world.

Soon the Mauna Loa scientists realized that humans were changing the atmosphere. They saw seasonal changes in carbon dioxide, and they also began to see a steady rise in the overall concentration. As spring begins in the northern hemisphere, vast reaches of vegetation come to life and soak up carbon dioxide. The concentration readings at Mauna Loa fell. With the coming of fall, leaves die and release some of their CO₂ back into the atmosphere. The concentration readings at Mauna Loa rose. Yet the decline in the fall didn't take CO₂ back to its starting point. The overall trend wasn't flat, it was pointing up. Yes, oceans absorbed some of the carbon dioxide from fossil fuel combustion, and, yes, the forests and fields of the Earth also absorbed some, but at least half stayed behind, a permanent addition to the atmosphere. Readings of 313 parts per million, in 1958, crept up by 4 parts per million over the next five years. Even in the brief space of five years, an upward trend was already evident.

Later on, scientists taking ice core samples from ice sheets in Antarctica were able to fill in an important missing piece. Antarctica's ice is layered. The layering process isn't quite the same as with tree rings, but ice layers too can tell a chronological story. Each year's modest snowfalls compress into very thin layers that leaves trace records of current carbon dioxide concentrations. Drill deep enough, analyze enough layers, and one can profile year by year carbon dioxide concentrations in the atmosphere from the present backward, for tens of thousands and hundreds of thousands of years. Once the last ice age ended, atmospheric carbon dioxide stabilized at 280 parts per million, and has been at about that level for more than ten thousand years.

280 parts per million may not sound like much, and in a way it is not. It isn't quite three parts in ten thousand, not quite three one hundredths of one percent. And yet a single part per million actually represents quite a lot of carbon dioxide. Turn it into dry ice and place it on a scales, and you'd find that it weighs 7.77 billion metric tonnes. In round numbers, the 280 ppm pre-industrial norm for carbon dioxide weighed a total of 2,175 billion metric tonnes.

And unlike the dominant gases of nitrogen and oxygen, which are completely transparent to infrared radiation, carbon dioxide is opaque to certain wavelengths of infrared. It isn't the atmosphere's most plentiful gas, but it is the atmosphere's most plentiful greenhouse gas.

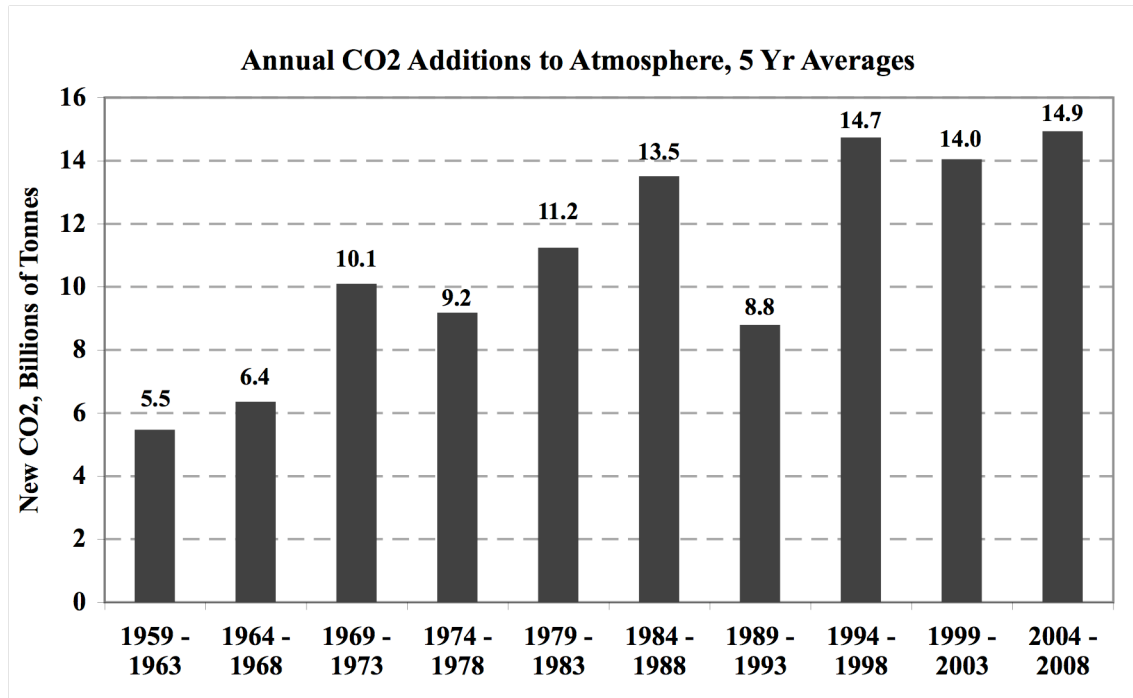
In 1958, though the scientists may not have realized it at the time, atmospheric CO₂ was already above its pre-industrial norm by almost thirteen percent, from 280 parts per million to 313 parts per million – roughly 2,430 billion tonnes. Today as I write, atmospheric carbon dioxide has grown by 38% from its pre-industrial norm, and is just now reaching the 3,000 billion tonne threshold.

Since Mauna Loa's first years in business, the rate of CO₂ growth has accelerated considerably, as the next chart makes clear. Note the annual take-up, in billions of metric tonnes a year, as shown below. Half a century ago, new CO₂ accumulated in the atmosphere at an average rate of 5.5 billion tonnes a year. Now, in the early years of the twenty-first century, the annual increase has almost tripled, to a current average of about 15 billion tonnes a year.

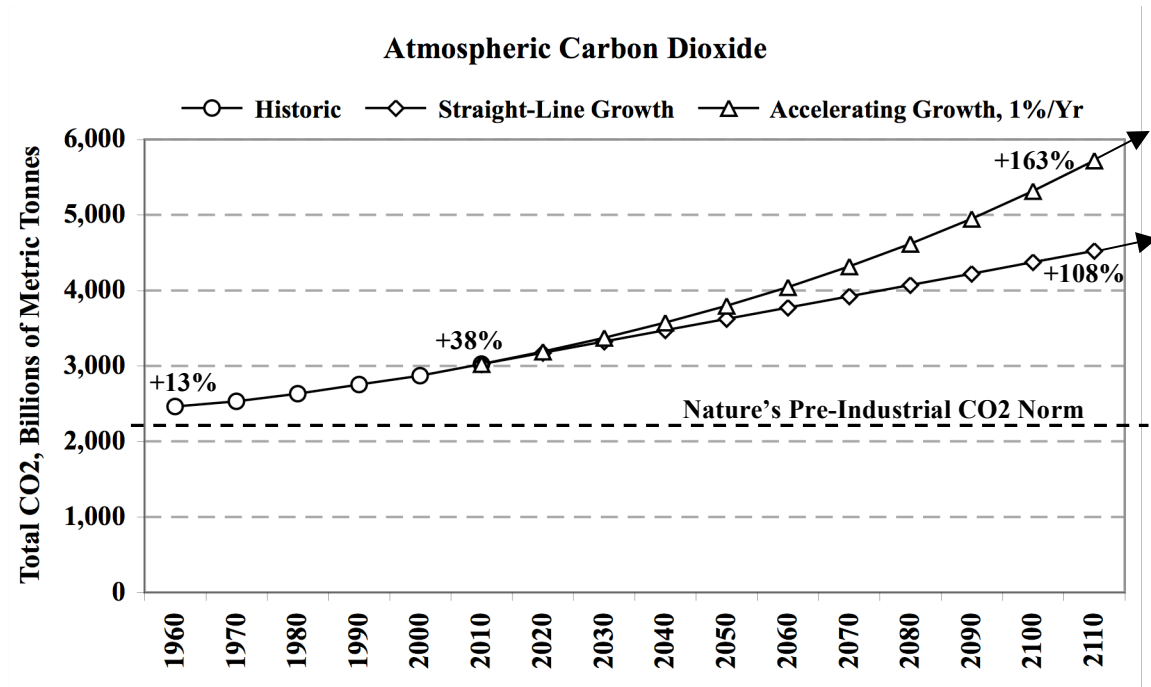
Note the dip in the early 90s. This plunge certainly caught my attention when I first ran these numbers. Scientists generally believe that this dip reflects the consequences of the 1991 Mount Pinatubo eruption in the Philippines, which belched a vast tonnage of sulfur aerosols into

the upper atmosphere. It turns out that a sulfur aerosol haze is plant friendly; for the next two years the world's vegetation took in considerably more carbon dioxide than normal, then the sulfur aerosols were washed out of the atmosphere and the CO₂ uptake by plants returned to its normal range.

The big picture is this. Carbon dioxide accumulated at a compound growth of two percent a year for the past half century.



Let's look forward, cautiously. In the next chart I offer two scenarios. The first scenario assumes Straight Line Growth in the total stock of CO₂, 150 billion tonnes each decade, with no compounding. The second assumes Accelerating Growth, compounding at only 1% a year. Each year's new CO₂ increment is one percent greater than the previous year's.



Today’s 38% overload is taken as the starting point. Straight-Line Growth, for the next century, raises the overload to 108%. Accelerating Growth takes the overload much higher, to 163%. In the first scenario, our descendants begin the next century with atmospheric CO2 more than doubled; in the second, the total stock of carbon dioxide is almost two and two thirds the pre-industrial norm. These two forecasts go to the heart of the energy and climate issue. If the overload is to reach 108%, or even 163%, if total CO2 is to be double or nearly triple its pre-industrial average, what will the temperature consequences and climate consequences be for planet Earth? What kind of irreversible damage might we bring upon ourselves and our descendants if we humans elect one of these scenarios? We know the templates. We know the replication processes. We know the raw consequences for rising levels of CO2 in the atmosphere. And we know the climate assets and ocean assets we wish to protect. As one might suspect, it seems likely that we are in a world of hurt. Let’s press on.

Heat Balance and Infrared Energy. At the root of the whole global warming issue is a strikingly simple proposition. Under normal circumstances, our Earth maintains a stable average temperature through the simple process of shedding just as much energy as it receives. When Energy Out, shed via infrared radiance, balances the Energy In, received from solar radiance, the Earth’s cooling system is spot on and its average temperature is reasonably stable. This is called Heat Balance.

Sunlight we understand because we can see it and we can feel it. Infrared radiance is not quite as obvious. But if you were an astronaut, floating in space, and if your eyes were capable of seeing light in the infrared part of the spectrum, you’d look at the Earth, a body that’s much much warmer than absolute zero, and you’d see it radiating an enormous amount of infrared light back out into space. Then you’d understand. “Ah, ha! Infrared Out is indeed just as intense as Visible Light In. So that’s how the Earth can be heated by the sun every day, 365 days a year, and yet not get hotter

and hotter and hotter. It uses infrared radiance to cool itself.”

It's a simple model. Now let's add a complicating factor. Imagine, for a moment, a one-time infusion of greenhouse gas into the atmosphere. Suppose a curious scientist finds a way to inject the atmosphere with a couple hundred billion tonnes of new carbon dioxide. He wants to write a paper for a peer-reviewed journal and he thinks it would be cool to do an experiment on the whole planet.

Here's the operating hypothesis, drawn from standard physics. With larger amounts of greenhouse gas in the atmosphere, not all the infrared radiance that normally escapes into space will make it through the thickened layer of greenhouse gases. An extra dollop of infrared will stay trapped within the planet's climate system. Heat balance has now been lost. Energy Out no longer offsets Energy In, and the planet starts to warm.

Warming is a slow process. Each day's new dose of additional trapped heat is quite small, compared to the total heat level of the planet. And the ocean functions as a thermal flywheel. Its thermal momentum is enormous. For the temperature of the climate system to rise, the temperature of the upper ocean must rise, and this is a very slow process. The atmosphere's capacity to store heat is but a tiny fraction of the ocean's heat storage. Still, as the day by day increments of excess heat add up, and find their way into the ocean, warming first the surface and then, through mixing, more of the upper part of the ocean, the temperature of the climate system follows suit. Not till the upper part of the ocean has been fully warmed will the Earth see a true and permanent rise in its average temperature. No one knows for sure what the delay factor is, but it could well be twenty or thirty years.

In due time, the heat of the ocean adjusts. With the upper parts of the ocean fully warmed, with the land areas duly warmed as well, the infrared radiance of the Earth finally rises to a high enough level that heat balance is restored. Energy Out once again offsets Energy In, and the temperature of the Earth stops rising. To the curious scientist, the long delay between the infusion of new CO₂ and the arrival of a new, higher temperature plateau is all part of the experimental design. Anything for a publishable research article.

As it happens, we humans are conducting a similar experiment, unintentionally, and with much less rigor. And, at present, with no ability to bring it to a halt. We're adding new infusions of carbon dioxide, 40 to 45 million tonnes of permanent new carbon dioxide each day, to the tune of 15 billion tonnes a year, 150 billion tonnes a decade, and if Business As Usual continues, the daily rate will only accelerate. The richer the mix of greenhouse gas in the atmosphere, the greater the imbalance between Solar In and Infrared Out.

To understand this in just a bit more detail, it is good to remind ourselves of another elemental scientific fact. Molecules of carbon dioxide are transparent to visible light. Photons of visible light, in shorter wavelengths than infrared, zip right through carbon dioxide without interference. In other words, no matter how much carbon dioxide we put in the atmosphere, it won't directly affect the amount of sunlight that reaches the surface of the Earth. But its presence does affect Infrared Out. In some wavelengths of infrared, carbon dioxide functions as a barrier. We say it is "opaque" to infrared rather than transparent. An infrared photon in the right wavelength is apt to be ensnared by a molecule of carbon dioxide; should this happen, its energy transfers instantly to the CO₂ molecule. What happens next? The carbon dioxide molecule might

transfer its new energy by conduction (as heat) to the next molecule it bumps into. Or its new dollop of energy might be re-radiated away as a new photon of infrared.

All this plays out in a complex setting of land and sea and air and clouds, with carbon dioxide's capacity to capture outbound infrared photons less significant in human regions where water vapor is abundant (water vapor is also a greenhouse gas) and more significant in regions, and seasons, of moisture free air. Still, with 825 billion metric tonnes of new carbon dioxide in the atmosphere already, thanks to human activity, with that total rising by 150 billion tonnes per decade, or more, carbon dioxide's role as a greenhouse gas will only become more and more significant as time goes on. Of themselves, these raw numbers foretell a warmer and warmer future.

But is carbon dioxide really all that important? The late astronomer Carl Sagan, in his final book, *Billions & Billions*, summed up the true importance of carbon dioxide and Earth's other greenhouse gases. He poses it as a simple question of physics. Given the heat of the sun and our planet's distance from the sun, how warm should one expect the Earth to be?

"What's coming in to warm the Earth depends on how bright the Sun is and how reflective the Earth is. (Whatever isn't reflected back into space is absorbed by the ground, the clouds, and the air. If the Earth were perfectly shiny and reflective, the sunlight falling on it wouldn't warm it up at all.) The reflected sunlight, of course, *is* mainly in the visible part of the spectrum. So set the input (which depends on how much sunlight the Earth absorbs) equal to the output (which depends on the temperature of the Earth), balance the two sides of the equation, and out comes the predicted temperature of the Earth. A cinch! Couldn't be easier! You calculate it, and what's the answer?

"Our calculations tell us that the average temperature of the Earth should be about 20° Celsius below the freezing point of water. The oceans ought to be blocks of ice and we all ought to be frozen stiff. The Earth should be inhospitable to almost all forms of life. What's wrong with the calculation? Did we make a mistake?

"We didn't exactly make a mistake in the calculation. We just left something out: the greenhouse effect. We implicitly assumed that the Earth had no atmosphere. While the air is transparent at ordinary visible wavelengths (except for places like Denver and Los Angeles), it's much more opaque in the thermal infrared part of the spectrum, where the Earth likes to radiate to space. And that makes all the difference in the world. Some of the gases in the air in front of us – carbon dioxide, water vapor, some oxides of nitrogen, methane, chlorofluorocarbons – happen to absorb strongly in the infrared, even though they are completely transparent in the visible. If you put a layer of this stuff above the surface of the Earth, the sunlight still gets in. But when the surface tries to radiate back to space, the way is impeded by this blanket of infrared absorbing gases. It's transparent in the visible, semi-opaque in the infrared. As a result the Earth has to warm up some, to achieve the equilibrium between the sunlight coming in and the infrared radiation emitted out. If you calculate how opaque these gases are in the infrared, how much of the Earth's body heat they intercept, you come out with the right answer. You find that on average – averaged over seasons, latitude, and time of day – the Earth's surface must be some 13° C above zero. This is why the oceans don't freeze, why the climate is congenial for our species and our civilization."¹

This bears repeating. Given our distance from the sun, if our planet had no atmosphere and no greenhouse gases, the sun isn't hot enough to stoke up the temperature of the Earth any further than minus twenty Celsius. The reason we are warmer, thirty-three degrees warmer on the Celsius scale and fifty-nine degrees warmer on the Fahrenheit scale, is that we have greenhouse gases in our atmosphere that trap the heat. Not till the average temperature of our climate system reaches 13 Celsius (55 Fahrenheit) does the Earth generate sufficient Infrared Out to fully offset Visible Light In. Is carbon dioxide important? Are greenhouse gases important? You bet. Without them, our

planet's average temperature would well below the freezing point. Yes. Greenhouse gases *are* important. Very important!

The Lesson Is Starting to Sink In

We are now discovering in a thousand ways how important this dynamic is, and how our modern powers of template replication give us the ability to have an impact on the present and future climate of our Earth. The anecdotal evidence for global warming comes from many different directions. Here is but a small sampling.

In March 2006, Washington Post reporter Doug Struck flew to Canada's Baffin Island, just two hundred miles away from Greenland. He landed at Pangnirtung's airfield, at the edge of the Cumberland Sound, and interviewed the town's Inuit villagers. Recent mid-winter changes at Pangnirtung were astounding. In past years, the month of February had typically shivered along at 20 below zero. By 2006, though, February's temperatures had climbed into the 40s. One Inuit had planted his fishing hut on the ice of Cumberland Sound, confident the hut would stay there for months. Three days later, the ice gave way beneath it and swept away not only the shack but \$6,000 in turbot fishing gear.²

Reporter Struck returned to the not-as-icy north a year later, and his stories from Greenland were equally remarkable. "Greenland's ice cap contains 800 trillion gallons of water and several outlet glaciers, huge rivers of ice that act as faucets from the ice cap. These faucets are running faster," reported researcher Don Voigt, at the Jakobshavn Glacier. "It's the fastest flowing glacier in the world." Reporter Struck summarized scientific thinking. "Scientists have a working theory for the glacier's speed. The Jakobshavn is churning toward the sea over land that forms a trough deeper than the Grand Canyon. As higher temperatures melt ice and snow on the surface, the water is pouring down through crevasses to the rock. There, it is acting as a lubricant, lifting and carrying the glacier faster toward the sea."³

On that same trip, Doug Struck also visited Daneborg, an ice patrol station on the northeast coast of Greenland. Every year, as winter approaches, ice closes the summer's open waters. The ice melts and the waters reopen in the spring. Soren Rysgard, a researcher for the Greenland Institute of Natural Resources summarized the new reality. "A decade ago, the water was open for 80 days. Now it stays ice-free for 140 days."⁴

Wall Street Journal reporter Douglas Belkin has reported that the Northwest Passage across the Arctic Ocean is now open in the summer time. Sailor Roger Swanson tried the passage in 2005 and his boat got stuck; he tried again in 2007 and it was clear sailing. Swanson is not alone, reported Belkin, the success count for Northwest Passage sailors in recent summers far exceeds anything seen for the last century.⁵

Meanwhile, in northern France, the Alsatian grape harvest has also been affected by rising temperatures. In 1978, reports Molly Moore of the Washington Post, the harvest started on October 16. In 2007, the harvest began almost two months earlier, on August 24.⁶

Average temperatures are trending upward, with year by year ups and downs as part of a general upward trend. When we are in an El Nino phase, temperatures rise faster; when we are in a high sunspot phase, temperatures also rise faster. If La Nina is in the ascendant, if sunspot activity is down, temperatures might decline just a notch, within the general upward trend. Climate zones

are shifting. Spring begins earlier than it did. Winters are more mild. Snowpacks melt earlier. Glaciers are shrinking, almost everywhere. The polar ice cap is shrinking, both in its thickness and in its extent. As sea ice around Greenland diminishes, glacial outflows pick up speed. Seismic shocks in the Greenland ice sheet are accelerating. Northern fields of permafrost are softening. If they thaw too much, if all the vegetation encased in the permafrost becomes warm enough to rot, the bacterial feast that will ensue will generate methane. The faster the thaw, the faster the bacterial feasting, the greater the methane. Given the total amount of plant matter frozen in the ice, the total methane released could climb to three or four or five hundred billion tonnes. Should we humans warm the Earth enough with all our fossil fuel carbon dioxide, it is conceivable that we could also trigger runaway permafrost thawing and massive, catastrophic methane release.

Put all these pieces together. Fossil fuel energy consumption is rising at an accelerating rate. The total stock of atmospheric CO₂ is climbing to levels not seen for millions of years. The greenhouse gas consequences for the temperature of the Earth suggest inexorably rising temperatures for some time to come. As the stock of atmospheric CO₂ rises higher and higher, so too will the corresponding oceanic concentrations of carbonic acid. Two vital environmental assets, our climate and our oceans, both suffering from the consequences of modern template replication as practiced by the energy sectors of almost every nation. Is it any wonder that so many scientists now urge citizens and their leaders to adopt alternative energy technologies and phase out fossil fuel?

We are at a decision point. As a society, have we the civic maturity to see reality plainly and decide responsibly? Can we provide the stewardship we are called to offer?

¹ Carl Sagan. *Billions & Billions*. pp 102-103. Random House. 1997.

² Doug Struck, Washington Post, "Inuit See Signs in Arctic Thaw." March 22, 2006.

³ Doug Struck, Washington Post, "In Arctic Ice, Lessons on Effects of Warming." June 7, 2007.

⁴ Doug Struck, Washington Post, "Icy Island Warms to Climate Change." June 7, 2007.

⁵ Douglas Belkin, Wall Street Journal, September 13, 2007.

⁶ Molly Moore, "In Northern France, Warming Presses Fall Grape Harvest Into Summertime." Washington Post. September 2, 2007.