Cold Cash, Cool Climate

Science-based Advice for Ecological Entrepreneurs

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THE SCOPE OF THE PROBLEM

"No battle plan survives contact with the enemy."

—HELMUTH VON MOLTKE THE ELDER

Climate change is probably the biggest challenge modern humanity has ever faced. It's bigger than World War II, because it will take decades to vanquish this foe. It's harder than ozone depletion, whose causes were far less intertwined with industrial civilization than fossil fuels and other sources of greenhouse gases. And it's more intractable than the Great Depression (or our current economic malaise) because financial crises eventually pass, assuming we learn from past mistakes and fix the financial system (again!).

Will we be able to avoid the worst effects of climate change? Nobody knows for sure, but in the face of an existential threat to human civilization, that's the wrong question. We must do whatever we can, as Winston Churchill said during World War II: "What is our aim? I can answer with one word: Victory—victory at all costs,[1] victory in spite of all terror, victory however long and hard the road may be; for without victory there is no survival."[2] We'll give it our best, and if it's not enough, we'll have to live with the consequences, but it shouldn't be because we lack understanding or fail to try. That's why I spent so much effort in the last few chapters explaining the details of the fix in which we now find ourselves: so we can face this challenge with clarity and full knowledge of how difficult it will be.

Let's try to put this problem in context. For about three decades, starting in 2012, we'll need to reduce global carbon emissions by on average almost 7% per year (compounded) to meet the constraints of the Safer Climate case, even as population and economic activity grow substantially, and poorer countries continue striving toward modernity. We'll also need comparable reductions in other greenhouse gases. This rate of emissions reductions is historically unprecedented, at least over decade-long time scales, but that doesn't mean it is impossible.

At the start of World War II, the US auto industry took *six months* to transition from building a few million autos a year to building planes and tanks for the war effort.[3] This shift wasn't easy or cheap, but it happened, and this example illustrates one important point about such rapid emissions reductions: they will likely result in some capital being scrapped before the end of its useful life. This is a problem from a political perspective, of course, but many modelers and analysts treat scenarios with premature capital retirements as infeasible. Based on the analysis below, I suspect strongly that we won't have that luxury, given the rapid reductions we'll need to achieve (and it will be particularly likely if we continue to build high-carbon infrastructure after 2012).

EMISSIONS SCENARIOS AND ROUTINE EQUIPMENT RETIREMENTS

The Safer Climate case implies about 1.7% per year carbon emissions reductions for the first decade after 2012 (compounded), with reductions of about 6.1%/year for the following decade and 10.6% per year for the decade after that. This back-loading of emissions reductions makes sense—it will take some time to gear up manufacturing capability to the needed scale. This rate of emissions reductions is aggressive, but not as aggressive as these percentages might imply at first glance.

As emissions actually start declining, a given percentage reduction represents a smaller *absolute amount* of equipment to be retired or replaced each year (because the percentage is relative to a smaller base). That's why it's often helpful to express reduction rates as a percentage of some base year value, in our case 2012. This tells us what fraction of 2012 emissions would have to be eliminated in any year to meet the constraints of the safer climate case, and it is proportional to the amount of capital equipment associated with those emissions (as long as there isn't much change in the carbon intensity of energy supply, which is true in the MIT no-policy case). Using this metric, the reduction rate for total carbon emissions in the first decade after 2012 is about 1.6% of year 2012 emissions every year (comparable to the exponential rate calculated above). Between 2022 and 2032 it's about 4% of year 2012 emissions per year, and from 2032 to 2042, it's about 3% of year 2012 emissions every year.

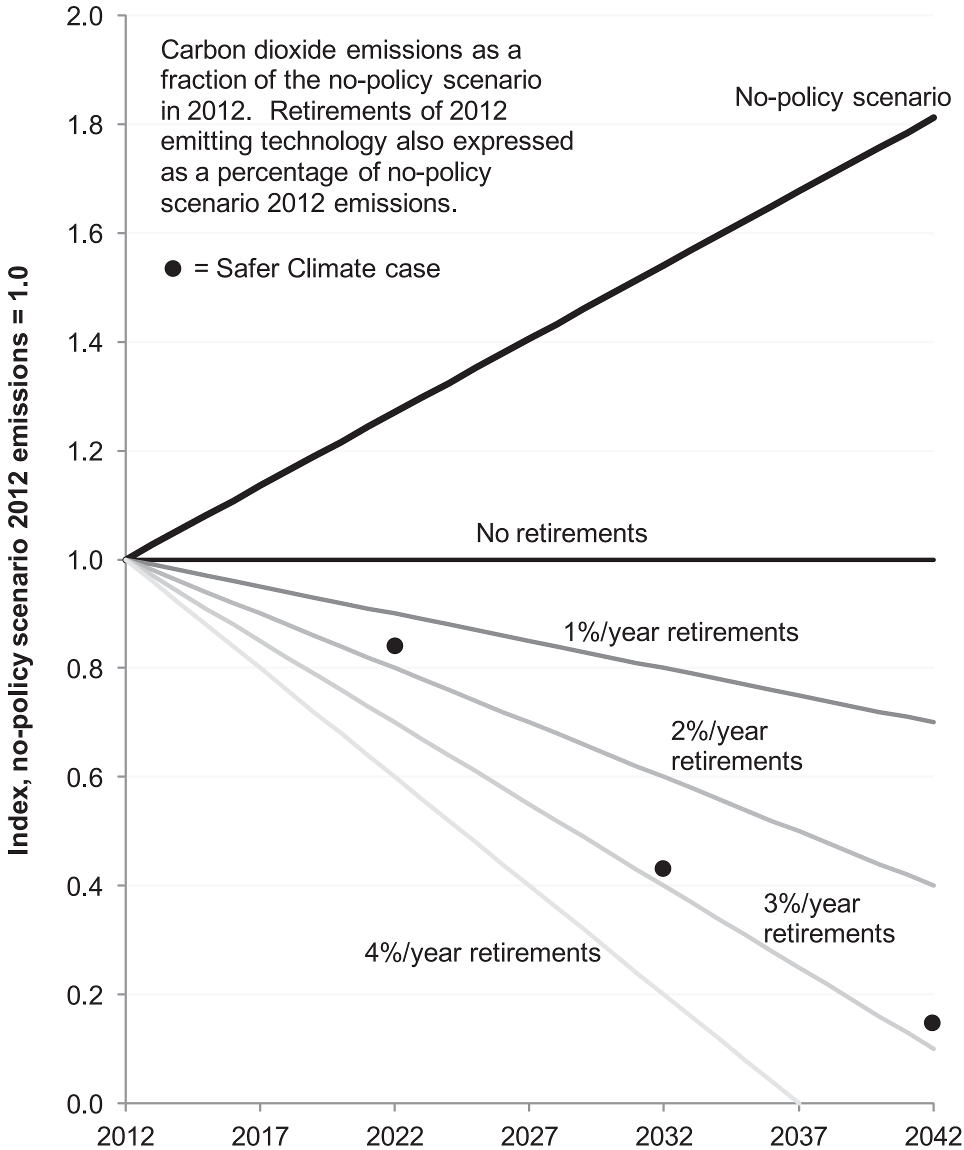
Figure 5-1 shows an illustrative calculation about energy-related carbon dioxide emissions to give you a feel for the magnitudes. I've taken the liberty of vastly simplifying the story to make a few key points. First, I've made a y-axis that shows carbon emissions as a fraction of 2012 emissions, so the lines on the graph are shown as an index with 2012 = 1.0. Next, I've plotted six lines. The topmost line is the MIT no-policy case emissions from 2012 to 2042 (which are the critical three decades in our Safer Climate scenario). That scenario shows average annual growth in emissions of 2.7% of year 2012 emissions.

Then I plotted a horizontal line to represent carbon emissions from the 2012 capital stock assuming there are no retirements of that equipment (or equivalently that it is replaced when retired with capital equipment that has exactly the same emissions characteristics as the 2012 stock). This line also corresponds to the emissions path that would prevail if all incremental energy service demand growth is met instead with energy technologies that emit no CO_2 starting in 2012, but equipment existing in 2012 continues to emit the same amount in perpetuity.

Finally, I plotted emissions pathways assuming different retirement rates for the 2012 capital stock, and assuming that all growth in emissions is met with zero emissions energy technologies, as is all energy service demand for retiring equipment that is displaced (retirement rates are expressed as a percentage of 2012 equipment stock). This thought experiment allows us to assess the rate of equipment retirement embodied in the Safer Climate emissions path, as shown below.

The retirement rates are related to the lifetimes of capital equipment. In the simplest case, a 1% per year absolute retirement rate means that the average lifetime of the capital stock is 100 years. Retirement rates of 2%, 3%, and 4% imply a lifetime of 50, 33, and 25 years, respectively, and are also expressed as a percentage of emissions in 2012 (this makes these retirement rates linear and absolute, as opposed to exponential, which is another simplification). In the real world there is great complexity in lifetimes and retirement rates of capital

FIGURE 5-1: Energy-related carbon dioxide emissions as a fraction of no-policy case emissions in 2012, assuming different retirement rates of 2012 capital stock and full replacement of retired stock and new growth with zero emission resources



Energy-related carbon dioxide emissions in the no-policy case track energy-related capital stocks because the emissions intensity of primary energy supply doesn't vary much in this case. The no-policy case emissions grow at 2.7% of 2012 emissions every year over this period (that corresponds to about a 2% compounded annual growth rate). The "No Retirements" case represents emissions from the 2012 capital stock assuming there are no retirements of that equipment (or equivalently that it is replaced when retired with capital equipment that has exactly the same emissions characteristics as the 2012 stock). Finally, I plotted emissions pathways assuming different retirement rates and assuming that all growth in emissions is met with zero emissions technologies, as is all demand for replacement equipment (retirement rates also expressed as a percentage of 2012 equipment stock).

equipment, but for the high-level calculation here, this rough approximation is good enough.

It's important to distinguish between capital stocks on the supply and demand sides, because their lifetimes are so different. Supply-side equipment, like power plants and refineries, typically lasts 25 to 50 years, while most end-use equipment is replaced in 10 to 20 years. Building shells last longer, typically 100 years for houses and about 50 years for commercial buildings, but these usually undergo major retrofits every 20 to 30 years. A weighted average lifetime of 33 years corresponds to the 3%/year retirement case, which happens to roughly mimic the later years of the emissions path for the Safer Climate case.

This graph repays careful study. The required rate of emissions reductions in the last decade of the Safer Climate case is near the limit of what can be expected by taking maximum advantage of natural stock turnover when replacing the year 2012 infrastructure (assuming a 33-year average lifetime).[4] Even more troubling, the slope of the emissions reductions curve in the Safer Climate case from 2022 to 2032 (as represented by the slope of a line connecting the points on the graph for those two years) is comparable to that of the 4%/year retirements case, with an implied capital lifetime of 25 years (shorter than much energy supply infrastructure). That's why I suspect that some capital will need to be scrapped to meet the emissions goals of the Safer Climate case. It will take some time before we are able to build enough zero-emissions infrastructure to fully replace the high-emissions equipment that retires every year and offset emissions growth as well, so some high-emissions infrastructure will surely be built in the next few years (although we should keep such investments to a minimum).

Figure 5-1 indicates the scope of the challenge we face. On average, every year between 2012 and 2042 we'll need to build the equivalent of about 6% of year 2012 energy infrastructure, but do it using zero-emitting technologies.[5] Of course, we would have had to build that infrastructure anyway; we'll just need to do it with low emissions technologies instead of standard ones, which is likely to be somewhat more expensive in the beginning. In later years economies of scale will take hold and the net direct cost of the energy system is unlikely to cost more than a few percent of GDP relative to the business-as-usual case, and have significantly lower societal costs from pollution and other externalities.[6]

IMPLICATIONS

This analysis has some important implications for our narrative, and for entrepreneurs confronting this challenge.

Stop building pollution-intensive infrastructure

The more high-emissions infrastructure we build in the next few years, the more we'll have to scrap in the next few decades, so we need to stop as soon as we can. That means no more new coal plants, no new shipping terminals to move coal overseas, no more pipelines to unconventional oil supplies, and no drilling for oil in the soon-to-be ice-free Arctic. It will be politically difficult to stop these projects, but once built it will be even harder to shut them down, so it's better that they never get built in the first place.

Some high-emissions infrastructure is already obsolete, so retire it!

About 15% of existing US coal plants (about 50 GW out of 300 GW total) are old, inefficient, polluting plants that were grandfathered under the Clean Air Act, so they have few or no pollution controls.[7] More than half of US coal plants are 35 years of age or older.[8] The total social cost of running many of these plants is higher than the cost of alternative ways of supplying that electricity (even without counting the damages from greenhouse gas emissions),[9] so they represent an obsolete capital stock from society's perspective. The most effective action we as a society can take would be to enforce existing environmental regulations, develop new ones (as the US EPA is now considering for mercury, mining, and other environmental issues), and charge these plants the full social cost of the damages they inflict upon us, which would double the cost per kWh of existing coal-fired plants even using low estimates of pollution costs. This will force lots of old polluting coal plants to retire, many others to reduce their hours of operation, generate lots of economic benefits in reduced health costs, give a boost to coal's competitors, and reduce greenhouse gas emissions, so it's a win all the way around.

Retrofit existing capital

Given the constraints imposed by the natural rate of equipment retirements, it's natural to consider ways of retrofitting existing equipment. For buildings, that might mean upgrading the shell and the heating/cooling systems at the same time as the internal space is improved to meet modern standards.[10] It could also mean eliminating standard incandescent lighting in virtually all applications, which can be done very quickly (and cost effectively, given how inefficient such lighting is). For power plants, that might mean repowering coal plants with natural gas. For industrial plants, that might mean adding combined heat and power to replace an old boiler. When practical, renovations represent another way to accelerate the turnover of the capital stock and to repurpose existing capital toward a less-polluting use.

It's not just the capital equipment that needs retrofitting, of course. Reevaluating how capital equipment is *operated* can yield big savings as well, because we need to retrofit our procedures and institutions in the face of new developments in technology and operational needs. Such "commissioning" can result in very large and cheap savings in both dollars and emissions, and it's a different and very effective way of repurposing existing capital stocks. A 2009 study reviewed such efforts in 300 existing US commercial buildings and found savings averaging 16% with a simple payback time of 1.1 years, just by operating the buildings differently (and making the buildings more comfortable as well).[11]

The entrepreneur's challenge

Since the constraints of the Safer Climate case will probably force us to scrap some capital stocks before the end of their useful lives, *it's your job to make existing capital stocks obsolete more quickly*. That means developing replacement products (and ways to retrofit existing buildings and equipment) that are so much better than current ways of delivering energy services that people are willing to scrap or repurpose that equipment to gain the advantages your product provides. That approach will allow us to minimize and sometimes sidestep the difficult political choices caused by premature retirements of existing capital.

As one example, consider light-emitting diode (LED) downlights that fit in those recessed ceiling cans that are so common in US homes. We installed almost 50 of these in our new house to replace our aging fixtures. We would have had to spend $20 to replace each fixture anyway, according to the contractor, and the LED fixtures we bought instead cost $50 each and fit right into the existing cans. Not only do they look better than what they replaced, they deliver bright and directional light, they come on instantly and dim just fine, their color rendition is so good that even my wife (who is a stickler in such matters) thinks they are great, and they will last 35,000 hours, which is probably 20 years at the rates that we use most of these fixtures.

The long lifetime (compared to at most a few thousand hours for incandescent bulbs and about ten thousand hours for compact fluorescents) was what put them over the top for us. We have relatively high ceilings throughout the house, so the prospect of climbing a tall ladder more than a dozen times a year was not an enticing one. The LEDs eliminate that hassle, and in fact are so good that they will surely encourage others to replace their fixtures before the end of their useful lives, because they are so much better than what they replace. And did I mention that they cut lighting electricity use by more than 80%?[12]

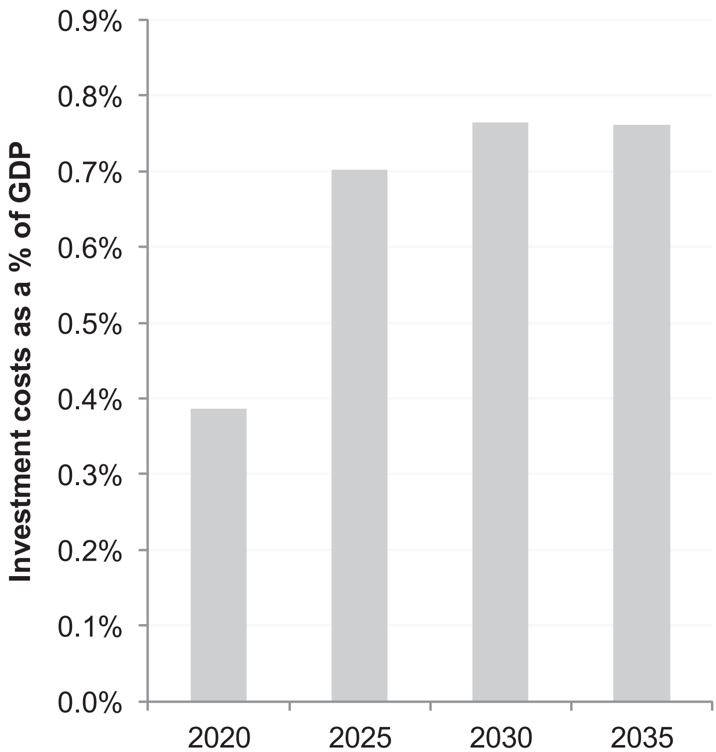
SCALE OF ENERGY SECTOR INVESTMENTS

One advantage of the "working forward toward a goal" approach is that it invites an assessment, however imprecise, of the investments needed to achieve that goal, in the same way as businesses use a big strategic goal against which to plan their investments and cash flows over time. The closest recent analogue to such an analysis for my Safer Climate case is one created by the International Energy Agency in its 2009 and 2010 *World Energy Outlooks*.[13] In those analyses, the IEA explicitly adopted a greenhouse gas concentration goal of 450 ppm CO_2 equivalent and estimated the scale of investments needed to achieve that goal.

Now as Chapter 4 indicated, I'm the last person to take literally the exact numbers from an economic forecast, but I'm going to summarize the results so you have a sense of the magnitudes involved. The IEA is explicitly doing a cost-effectiveness analysis for meeting a warming target, not a more traditional benefit-cost analysis, so their approach is at least roughly consistent with the methods I advocate earlier in the book. They carefully tally energy sector investments at a detailed level, just like you'd do in a good business plan, so I have some faith that their numbers are in the ballpark.

The 2010 *World Energy Outlook* study gives estimates of additional energy sector investment spending in their climate stabilization case, which I express as a percentage of GDP in a given year in **Figure 5-2**. These numbers include both supply- and demand-side spending, but do not account for the energy

FIGURE 5-2: Global annual additional investment spending on low-carbon energy technologies in the International Energy Agency climate stabilization case compared to the Current Policies scenario



SOURCES: Investment costs taken from IEA. 2010. World Energy Outlook 2010. Paris, France: International Energy Agency, Organization for Economic Cooperation and Development (OECD). November 9. [http://www.worldenergyoutlook.org/]. GDP taken from US DOE. 2011. International Energy Outlook 2011. Washington, DC: Energy Information Administration, U.S. Department of Energy. DOE/EIA-0484(2011). April 26. [http://eia.doe.gov/oiaf/ieo/]

savings associated with many of the demand-side investments (those savings would reduce the net costs). The IEA stabilization case is not quite as aggressive as the Safer Climate case, but it's close enough, and it tells us that the increase in overall investment is less than 1% of GDP in the out years of the forecast. When all macroeconomic costs are tallied, this study finds costs of about 3.2% of GDP in 2035 (with significantly lower percentage impacts before that date), but it is not clear if the economic benefits of reduced emissions of particulates, sulfur, nitrogen oxides, and other pollutants are included in that figure.[14]

The key result is that the increase in costs for this scenario is a few percent of GDP in the later years of the forecast, which is comparable to other credible macroeconomic studies of achieving similar stabilization levels.[15] While the exact number is uncertain, it's clear that it's not 30% of GDP, which is the main point I'd like you to come away with (it is probably lower than 3% because of the various factors I discuss in Chapters 3 and 4). Reducing GDP by a few percent means delaying reaching a certain level of GDP by about a year at the expected growth rates in GDP for the *World Energy Outlook*, and this seems to me to be a small price to pay to avoid the serious effects of climate change I outline earlier in the book.

UNDERLYING DRIVERS OF EMISSIONS GROWTH

Another way to think about the scope of the climate challenge is to examine the underlying drivers of emissions. For carbon dioxide, the main terms are land-use changes, cement production, and combustion of fossil fuels. For all three (as well as for many of the non-CO_2 warming agents), economic activity and population growth directly drive those emissions, but the way we choose to manage those drivers also plays a role. For example, cement can be produced in ways that significantly reduce CO_2 emissions,[16] and the productivity of agriculture can be improved in many ways,[17] making it less likely that additional forested land would need to be cleared for these purposes. Social and policy changes can also affect emissions growth, for example, by reducing population growth,[18] changing the composition of GDP toward less carbon-intensive development,[19] or changing the types of foods we eat.[20]

It is common to think about energy-related CO_2 emissions (which are by far the largest source of carbon emissions) as the product of 4 terms: population, wealth, energy intensity, and carbon intensity. I show these terms in **Equation 5-1**:

$$\text{Carbon emissions} = \text{Population} \times \frac{\text{GDP}}{\text{Person}} \times \frac{\text{Energy}}{\text{GDP}} \times \frac{\text{Carbon}}{\text{Energy}} \qquad (5\text{-}1)$$

Where

- Carbon emissions = total energy-related carbon emissions (in billions of metric tons of carbon)

- Population = the number of people (in millions);
- GDP/Person = the average wealth of each person, expressed as Gross Domestic Product (in inflation adjusted dollars per person);
- Energy/GDP = the amount of total primary energy needed to generate one unit of wealth (in Exajoules or EJ [10^{18} joules] per million dollars); and
- Carbon/Energy = the carbon intensity of primary energy supply (in billions of metric tons of carbon per EJ of primary energy).

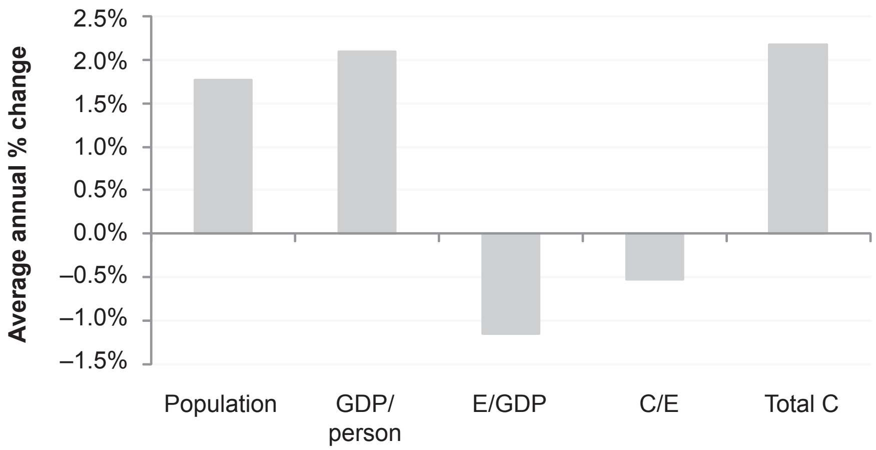
This equation is known as the Kaya identity. There are more complicated forms of it[21] and there are complexities in applying it[22], but for our purposes here it's good enough. It shows that changes in population, wealth, energy intensity of economic activity, and carbon intensity of energy supply all influence total emissions.

You don't need to know much about the details to put it to use. For example, if you hold everything else constant but double wealth per person over some time period, you'd expect energy-related carbon emissions to also double. If you double wealth per person but halve energy use per GDP (by capturing more energy efficiency) then you'll keep carbon emissions constant.

You can break down annual average growth in energy-related carbon emissions into component parts that correspond to each term in the Kaya identity. **Figure 5-3** shows such an analysis for 1950 to 2000, using data for the world as a whole[23] (in principle, such calculations should be done by country or state, because specific circumstances vary so much). Population and wealth per person both grew around 2%/year, while the energy/GDP ratio fell a little more than 1%/year. Combined with about 0.5%/year decline in the carbon intensity of primary energy supply, growth in total global energy-related carbon emissions was about 2%/year over this period. The percentage growth terms add up to the total annual growth in emissions, which makes it easy to keep track of which terms are contributing most to the growth.

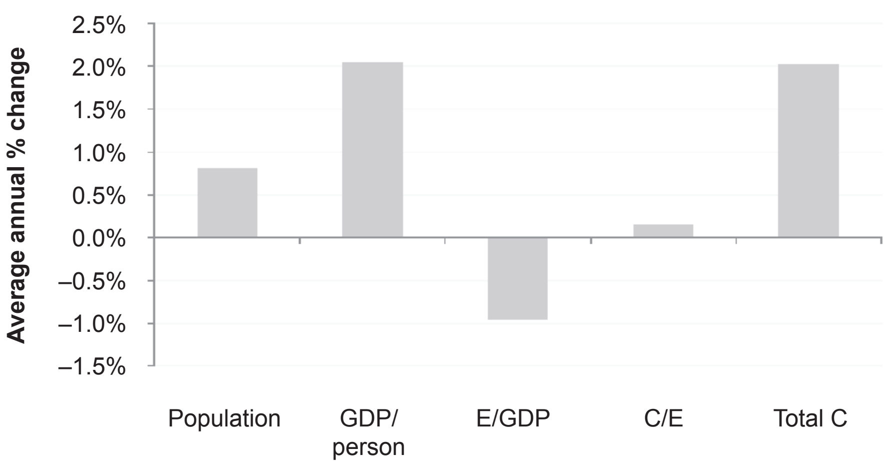
Figure 5-4 shows the same calculations for energy-related carbon emissions in the MIT "no-policy case" from 2000 to 2050, also showing 2%/year growth. The main differences are that the historical data show much higher rates of growth in population (because the world hasn't yet gone through the demographic shifts anticipated by the UN population forecasts built into the MIT results) and the carbon intensity of energy supply decreases in the histori-

FIGURE 5-3: Average annual rate of change in the drivers of global energy-related carbon emissions, 1950 to 2000



SOURCE: Data from Grubler, Arnulf. 2008. "Energy transitions." In Encyclopedia of Earth. Edited by C. J. Cleveland. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. [http://www.iiasa.ac.at/~gruebler/Data/EoE_Data.html]

FIGURE 5-4: Average annual rate of change in the drivers of global energy-related carbon emissions in the MIT no-policy case, 2000 to 2050



cal data while increasing in the forecast (probably because of the strong projected growth in energy demand in China, India, and other developing countries with significant coal reserves).

There are myriad opportunities for entrepreneurial innovation affecting each of the four terms of the Kaya identity, so don't limit your thinking to just improvements in energy efficiency or the carbon intensity of energy supply. New ventures can reduce population growth (by bringing vaccines, clean water, family planning, or education to those without them), change the nature of GDP growth (by affecting settlement patterns, eating habits, and other consumer choices), or affect several drivers all at once. To achieve the emissions path represented by the Safer Climate case, we'll need to reduce population growth and change the way we generate GDP, in addition to increasing rates of improvement in energy and carbon intensity severalfold over historical trends.

AN EVOLUTIONARY APPROACH

We can't know exactly how much fixing this problem will cost or how much effort it will take, but we know it won't be easy. In the absence of perfect foresight, we can adopt an evolutionary and adaptive approach, and use indicators to see if we are on track to meet the demands of the Safer Climate case in each year.[24] One important indicator is actual emissions of greenhouse gases and other warming agents, which in most cases can be assessed a relatively short time after a calendar year has ended. Rates of change in average surface temperatures are another important indicator, as are glacial melting rates. For energy-related emissions, we can track the underlying drivers of emissions growth identified in the Kaya identity, to see how they are progressing compared to our initial expectations. That calibration too can yield important insights.

If we aren't meeting the Safer Climate emissions in any year (or if temperatures rise more rapidly than expected, given actual emissions), that means we'll need to increase the vigor of our efforts. If one of the Kaya identity components is changing in ways different than we expected, we'll need to focus more attention on that one or make up for it in activities affecting the other terms.

This approach places greater burdens on our ability to respond dynamically to events as they unfold, a skill that is not always manifest in governments and other large institutions. We will, however, need these institutions (and the people in them) to learn how to adapt, and to do so in short order.

CONCLUSIONS

The climate challenge is unlike any other humanity has ever faced. We'll need every trick we've got to meet it in a way that will make our descendents proud, and there's simply no more time to waste. Entrepreneurs can help by making low-emitting products that are so good that people are happy to retire their existing equipment, thereby increasing the rate at which existing capital becomes obsolete. They can also affect the key drivers of emissions growth, like population and the structure of economic activity, in ways that can make the achievement of climate stabilization goals easier. And of course, they can create new ways of meeting human needs that emit many times fewer pollutants by aggressive use of whole system integrated design. I'll explore how to find and evaluate opportunities like these in the next chapter.

CHAPTER 5: KEY TAKEAWAYS

- The cost to society of meeting the constraints of the Safer Climate case is at most a few percent of world GDP, but that cost increases sharply with each year of delay.
- It is likely that some capital in the energy sector will have to be scrapped in the next few decades, given the rate of emissions reductions required for the Safer Climate case.
- One important role for the entrepreneur is to accelerate obsolescence of existing capital by making products that are so much better than what they replace that people will happily scrap their existing equipment to have it. That means higher quality, better services, lower emissions, and lower costs, all in one package.
- There will be opportunities in building new products and services but also in retrofitting old equipment as well as modifying our behaviors and institutions. All of these are fruitful areas for entrepreneurial innovation.

"It is not the critic who counts, not the man who points out how the strong man stumbled, or where the doer of deeds could have done them better. The credit belongs to the man who is actually in the arena; whose face is marred by dust and sweat and blood; who strives valiantly; who errs and comes short again and again; who knows the great enthusiasms, the great devotions, and spends himself in a worthy cause; who, at the best, knows in the end the triumph of high achievement; and who, at worst, if he fails, at least fails while daring greatly, so that his place shall never be with those cold and timid souls who know neither victory nor defeat."

— THEODORE ROOSEVELT