

The Race of Our Lives Revisited¹

Jeremy Grantham



Introduction

It was always going to be difficult for us – Homo sapiens – to deal with the long-term, slow-burning problems that threaten us today: climate change, population growth, increasing environmental toxicity, and the impact of all these three on the future ability to feed the 11 billion people projected for 2100.

Our main disadvantage is that our species has developed over the last few hundred thousand years not to address this kind of long-term, slow-burning issue, but to stay alive and well-fed today and perhaps tomorrow. Beyond that we have a history of responding well only to more immediate and tangible threats like war.

Ten thousand years ago, or even a hundred years ago, these problems were either mild or non-existent. Today they are accelerating to a crisis. And at just this time, when of all times we could use a lucky break, our luck has deserted us. We face a form of capitalism that has hardened its focus to short-term profit maximization with little or no apparent interest in social good just as its power to influence government and its own fate has grown so strong that only the biggest most powerful corporations and the very richest individuals have any real say in government. To make matters worse, we have an anti-science administration that overtly takes the side of large corporations against public well-being, even if that means denying climate change and stripping the country of the very regulations designed to protect us. The timing could not be worse. It is likely we in the US will lose – indeed, we are losing already – the stable and reasonable society that we have enjoyed since The Great Depression. Beyond the US, the risks may be even greater, with the worst effects in Africa – threatening the failure of an entire continent.

Our one material advantage is in the accelerating burst of green technologies, which has been better than anyone expected 10 or even 5 years ago and that may in the future be able to offset much of the accelerating damage from climate change and other problems. Yet despite these surprising technological advances, we have been losing ground for the last few decades, particularly in the last few years. Somehow or other we must find a way to do better. We must expand on our strengths in technology while fighting our predisposition toward wishful thinking, procrastination, and denial of

¹This paper uses much of the same material presented at this year's Morningstar Investment Conference in Chicago in June and at London School of Economics in April 2018. Please make allowances for its conversational style. I have attempted to adapt and expand this version for the general public. And please remember you don't have to read this in one sitting. The original "Race of Our Lives" is part of the GMO Quarterly Letter from April 26, 2013 and can be read at www.gmo.com.

inconvenient long-term problems. We must also find inspirational leadership, for without it this race, possibly the most important struggle in the history of our species, may not be winnable. It is about our very existence as a viable civilization. We will need all the leadership, all the science and engineering, all the effort, and all the luck we can muster to win this race. It really is the race of our lives.

Part I: Summary of the Argument

I'm going to give you a broad overview of this topic first, then follow with considerable back-up data and supporting exhibits.

You could call this the story of carbon dioxide and Homo sapiens. You may not know, but if we had no carbon dioxide at all, the temperature of the Earth would be minus 25°C – a frozen ball with no life with the possible exception of bacteria. That crucial 200 to 300 parts per million of carbon dioxide has taken us from that frozen state to the pretty agreeable world we have today. CO₂ is therefore, thank heavens, a remarkably effective greenhouse gas. The burning of fossil fuels, which is the main cause for increasing CO₂ and warming the world, has played a very central role in the development of civilization. The Industrial Revolution was not really based on the steam engine – it was based on the coal that ran the steam engine. In a world without coal, we would have very quickly run through all our timber supplies, and we would have ended up with what I imagine as the great timber wars of the late 19th century. The demand for wood would have quickly denuded all of the great forests of the world, and we would have returned to where we were at the time of Malthus, living at the edge of our capability, enduring recurrent waves of famine along with every other creature on the planet. A few good years, the population expands; a few bad years, we die off.

A gallon of gasoline can do work equivalent to 400 hours of manual labor. This extraordinary advance meant that the ordinary middle class had the power that only kings had in the distant past. And what it did, this incredible gift of accumulated power from the sun over millions of years, was to create an enormous economic surplus that catapulted civilization forward in terms of culture and science. Above all, agriculture has benefited, allowing our population to surge forward.

The sting in this tale, however, is that this has left us with 7.5 billion people today, going on a predicted 11 or so billion by 2100. Such a large population can only be sustained by continued heavy, heavy use of energy. Fossil fuels will run out, destroy the planet, or do both. The only possible way to avoid this outcome is rapid and complete decarbonization of our economy. Needless to say, this will be an extremely difficult thing to pull off. It requires the best of our talents and innovation, which miraculously, it may be getting. It also needs much better than normal long-term planning and leadership, which it most decidedly is not getting yet. In theory, Homo sapiens can easily handle this problem; in practice, it will be a very closely run race. We should never underestimate technology but also never underestimate the ability of us humans to really mess it up.

If the outcome depended on our good sense, if we had, for example, to decide in our long-term interest to take 5% or 10% of our GDP – the kind of amount that you would need in a medium-sized war – we would of course decide that the price was too high until it would be too late. It is hard for voters, and therefore politicians too, to give up rewards now to take away pain in the distant future, particularly when the pain is deliberately confused by distorted data. It is also hard for corporations to volunteer to reduce profits in order to be greener. Given today's single-minded drive to maximize profits, it is nearly impossible.

But technology, particularly the technology of decarbonization, has come surging in to help us. This is the central race. Technology, in my opinion, will in one sense win. If we were able to look ahead

40 years, I'm confident that there would be a decent sufficiency of cheap green energy on the planet. In 80 years perhaps it's likely we would have full decarbonization. Lack of green energy will not be the issue that brings us down. If only that were the end of the story. The truth is we've wasted 40 or 50 years since the basic fact about manmade serious climate damage became known. We're moving so slowly that by the time we've fully decarbonized our economy, the world will have heated up by 2.5°C to 3°C, and a great deal of damage will have been done. A lot more will happen in the deeper future due to the inertia in the environmental system: if we no longer produce even a single carbon dioxide molecule, ice caps, for example, will melt over centuries and ocean levels will continue to rise by several feet.

I don't worry too much about Miami or Boston being under water – that's just the kind of thing that capitalism tends to handle pretty well. The more serious problem posed by ocean level rise will be the loss of the great rice-producing deltas: the Nile, the Mekong, the Ganges, and others, which produce about a fifth of all the rice grown in the world. Agriculture is in fact the real underlying problem produced by climate change. Even without climate change, it would be somewhere between hard and impossible to feed 11.2 billion people, which is the median UN forecast for 2100. It will be especially difficult for Africa.

With climate change, there are two separate effects on agriculture. One is immediate: the increased droughts, the increased floods, and the increased temperature reduce quite measurably the productivity of a year's harvest. Then there's the long-term, permanent effect: the most dependable outcome of increased temperature is increased water vapor in the atmosphere, currently up over 4% from the old normal. This has led to a substantial increase in heavy downpours. It is precisely the heavy downpours that cause soil erosion. In regular rain, even heavy rain, farmers lose very little soil. It is the one or two great downpours every few years that cause the trouble. We're losing perhaps 1% of our collective global soil a year.² We are losing about a half a percent of our arable land a year.³ Fortunately, it is the least productive half a percent. It is calculated that there are only 30 to 70 good harvest years left, depending on your location.⁴ In 80 years, current agriculture will be simply infeasible for lack of good soil. We must change our system completely to make it sustainable, which, critically, involves reducing erosion to almost zero by using no-till or low-till farming combined with cover crops. Because these are significant changes for a conservative community, it will take decades and we've barely started.

Happily, there are impressive advances in new technology in agriculture too. From intensive data management that tells us square meter by square meter exactly what is going on, where the nutrients are lacking and where more water is needed; to the isolation of every single micro-organism that relates to a plant. This race, too, is finely balanced.

A separate thread also closely related to fossil fuels is that we've apparently created a toxic environment, not conducive to life, from insects to humans as we will see. We must respond by a massive and urgent move away from the use of complicated chemicals that saturate our daily life.

A subtext to all of what I have to say here is that capitalism and mainstream economics simply cannot deal with these problems. Mainstream economics ignores natural capital. A true Hicksian⁵ profit requires that the capital base be left completely intact and only the excess is a true profit. Of course, we have not left our natural capital base intact or anything like it. The replacement cost of the copper,

² D.R. Montgomery, *Dirt: The Erosion of Civilizations*, University of California Press, 2007.

³ Pimentel and Burgess, "Soil Erosion Threatens Food Production," *Agriculture*, August 2013.

⁴ 2015 International Year of Soil Conference, UN Food and Agriculture Organization.

⁵ Sir John Richard Hicks is considered one of the most important and influential economists of the 20th century.

phosphate, oil, and soil – and so on – that we use is not even considered. If it were, it's likely that the last 10 or 20 years (for the developed world, anyway) has seen no true profit at all, no increase in income, but the reverse.

Capitalism also has a severe problem with the very long term because of the tyranny of the discount rate. Anything that happens to a corporation over 25 years out doesn't really matter to them.⁶ Therefore, in that logic, grandchildren have no value. Corporations also handle externalities very badly. Even the expression "handle badly" is flattering, for corporations typically don't handle them at all, they're just completely ignored. When they are not ignored it is usually because of direct or implied pressure from customers collectively. We deforest the land, we degrade our soils, we pollute and overuse our water, and we treat our air like an open sewer. All of this is off the balance sheet and off the income statement. Worse, any sensible response is deliberately slowed down by skillful programs of obfuscation, well-funded by fossil fuel interests and their allies. These deliberate obfuscators were known as the merchants of doubt when the problem was tobacco. (One of those merchants, MIT professor Richard Lindzen, actually went seamlessly from defending tobacco – where he famously puffed cigarettes through his TV interviews – to denying most of the problems of climate change.) This does not happen in China, India, Germany, or Argentina. This is unique to the English-speaking, oily countries – the US, the UK, and Australia – where the power of the fossil fuel interests is used to influence both politics and public opinion.

I think I understand the capitalist argument. Milton Friedman, a patron saint of today's brand of capitalism, famously said "There is only one social responsibility of business...to increase its profits (so long as it...engages in open and free competition without deception or fraud)." It makes for a simple enough world. But it is very different from the US I came to in 1964, which (except civil rights) was with hindsight perhaps at the sweet spot of the social contract. CEOs were content with 40 times the income of their average workers (as Japan still is) and not today's 300 times. Corporations acted as if they really had obligations to the cities and states in which they operated. And, of course, to their country. This is true to a much smaller degree today. Corporations also acted as if they had real responsibility to their workers: to prove it they set about designing generous, i.e., expensive, well-managed defined benefit pension funds. Which they did not have to do. Today they claim, despite much higher profit margins, that they cannot afford them. The US as a whole also projected an idea of a global social contract – whenever the cold war would allow it – to promote the idea that ethical behavior had value (there were some miserable exceptions, but mostly it tried). It was always the US leading the way in promoting cooperative international trade, to enormous beneficial effect globally.

Today both of these contracts appear to have been torn up and climate change is the epitome of what those who did the tearing up really hate: it occurs everywhere and very slowly. It is the ultimate Tragedy of the Commons: so it can only be dealt with by government leadership and regulation. All this is anathema to the new regime of maximizing an individual country's advantage and short-term corporate profits. Yet however much libertarians may hate regulation – and in general I am sympathetic – when it comes to climate change it is simple. There is no other way.

As a footnote to the data provided, I will also examine the long and widely held view that any form of divestment is guaranteed to ruin performance. And together we will discover this view is completely inaccurate.

⁶ At a corporate discount rate of 15%, a common enough hurdle for new investments – today's value of \$1 earned 26 years from now is two and a half cents.

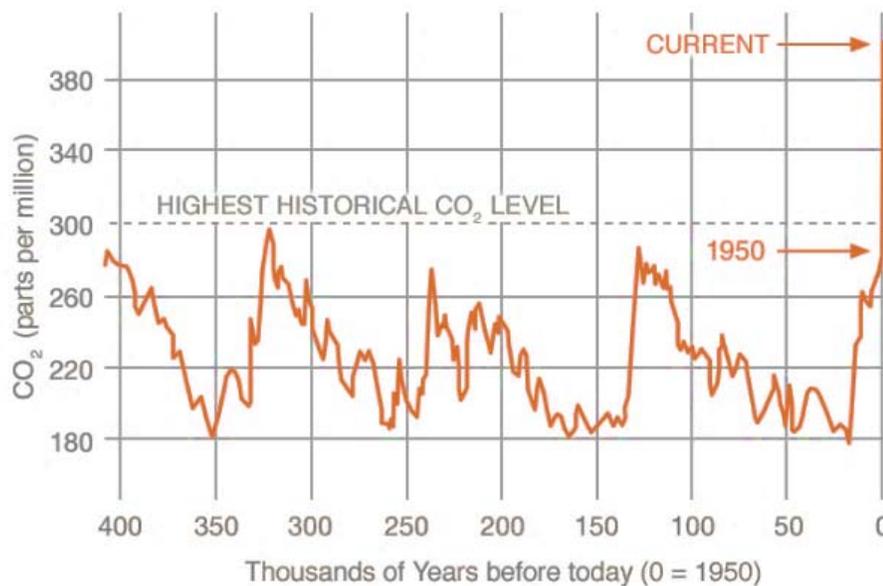
Part II: Back-up Data

Climate Change Damage Is Accelerating

Exhibit 1 is the famous chart you might have seen used by Al Gore. It shows that for hundreds of thousands of years, the Earth's atmosphere has had 180 to 300 parts per million of carbon dioxide. At 180 parts per million, we had ice ages (in the popular parlance) where, for example, 20,000 years ago New York was over a thousand feet deep in ice: enough to cover any building there today. At the previous highs of 280 parts per million, we had the interglacials, four of them, where our species benefited from the temperate and relatively stable environment we have enjoyed for the last few thousand years: a remission from cold that allowed for and facilitated the growth of civilization in the last 12,000 years. (Just for the record, 75% to 80% of the last 400 thousand years were spent in the "ice ages" and only 20% to 25% were in the warmer interglacials.)

In 1950, carbon dioxide levels were pretty much at the top of this historical range, and we were perhaps ready to slide into a new ice age in the next few thousand years. Then, bang, we added another 120 parts per million in the blink of an eye! We have added the same amount that separates the bottom of glacial phases from interglacials, and we've added it in just 70 years. It is a dramatic and reckless experiment. The best word to describe it is feckless. We are going to add another 120 parts per million, I give you my personal guarantee. By the time we finish, we will have tripled the difference between an ice age and an interglacial. We must sincerely hope it is not worse than that.

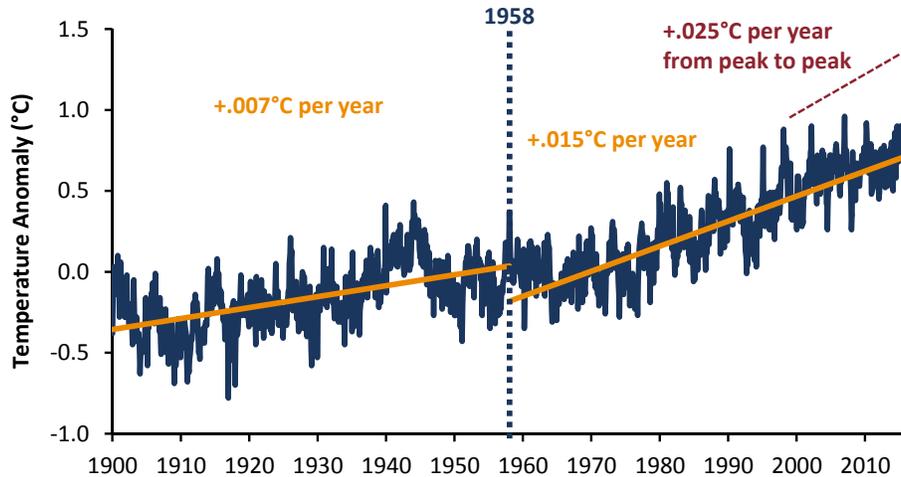
Exhibit 1: Historical CO₂ Levels (Reconstruction from Ice Cores)



Source: NOAA

I'm proud to say I did Exhibit 2 about four and a half years ago because back then the scientists would not use the word "accelerate." Scientists can be pretty chicken: not unreasonably given they are anxious to protect the dignity of science; they also desperately don't want to be caught out exaggerating. With climate change they tend to underestimate and then are surprised by accelerating data. I sympathize with them – in science, overstatement is often dangerous – but in climate change work understatement can be very, very dangerous if it leads politicians to underreact in their policies.

Exhibit 2: Global Surface Temperature Compared to 1951-1980 Average



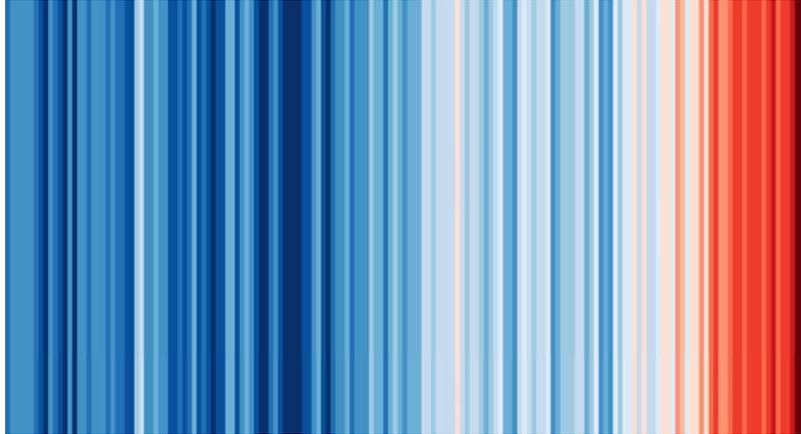
As of 8/31/16
Source: NASA Goddard Institute for Space Studies, GMO

I have kept an informal check on the number of peer-reviewed articles where the conclusion is a change in the climate outlook – with much help from the “Carbon Brief” and many others. My informal count is that about 80% conclude that, from the specialized work they have just done, the climate outlook is likely to be worse than consensus. The remaining 20% is either compatible with existing consensus or predicts a mitigating factor, a recent example of which would be that accelerating ice melting in Antarctica leads to an unexpectedly rapid rise in the bedrock from the reduced weight of the ice, which slows the rate of ice cap melting. But an 80-20 ratio in peer-reviewed science is pretty scary in itself. In stock market work – even economics – when a trend is systematically underestimated time after time models usually change to catch up. Climate science to date has been content to lag. What I must concede, though, is that since the US presidential election and the declaration of open war not just on climate science but science and research in general, the tone of climate research has toughened up considerably and become more realistic, and the term “acceleration,” almost overnight (and considerably overdue), has become commonplace.

Still, the data in Exhibit 2 is clear. The trendline through the first 50 years of the last century is an increase of 0.007°C per year. In the second half, the trend had doubled to 0.015°C per year. Then between the two El Niños – climate events that cause a temporary surge in global heat – of 1998 and 2016 (like lining up the top of bull markets), the temperature increased at an average of 0.025°C per year.

Exhibit 3 shows what that looks like in color coded form from 1850 to 2017. Deep red goes up to +0.6°C above long-term average and dark blue goes down to -0.6°C below. This is an exceptionally clear way of showing data. Yes, there’s a little variability, but my, oh my, the dark red is all on the right.

Exhibit 3: Global Annual Temperatures, 1850-2017 – Color-Coded

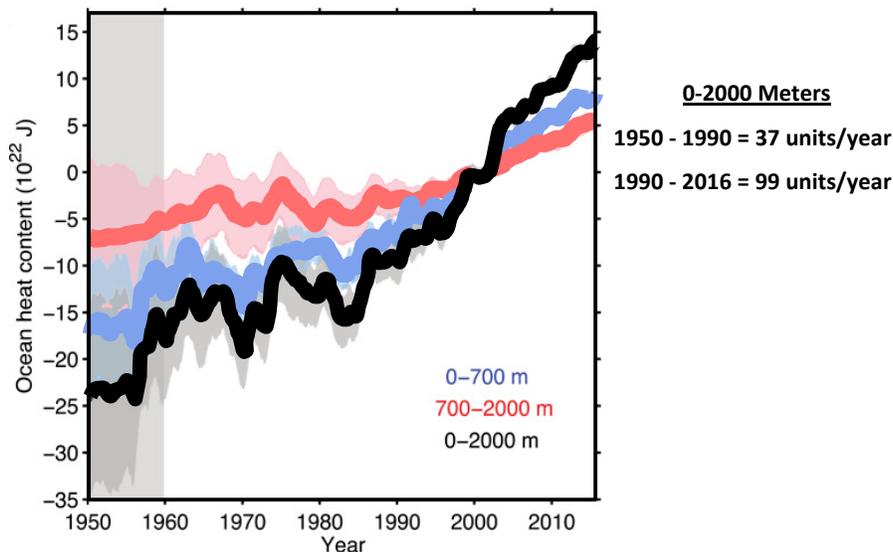


Source: Ed Hawkins, Climate Lab Book

This exhibit reminds me of all the talk about pauses – the claim that 1998 was supposedly the top of the warming, which had then stopped, a favorite refrain of both deniers and “don’t worry-ers.” This argument was still remarkably in full force as late as 2013 and is repeated even now. Indeed, a famous British politician, former Chancellor of the Exchequer, Lord Lawson, said on BBC Radio 4 this past April that the previous 10 years had not had any warming. He was not just wrong. The last 10 years were 10 of the hottest 11 years in history and contained the 3 hottest years ever. Please explain to me, if anyone knows, why these people say stuff like that. I have no idea. Perhaps they hate their grandchildren.

Exhibit 4 shows ocean temperature, which is accelerating even more than air temperature. The oceans absorb 93% of all the heat, with the rest spread between dry land and the air.⁷

Exhibit 4: Ocean Heat Content (in Joules)



Source: “Improved Estimates of Ocean Heat Content from 1960 to 2015,” Cheng et al, Science Advances, March 10, 2017

⁷D. Laffoley and J.M. Baxter (editors), “Explaining ocean warming: Causes, scale, effects and consequences,” IUCN, September 5, 2016.

The black line from the bottom left to the top right shows the heat energy of the ocean from the surface to 2,000 meters deep. From 1950 to 1990 it warmed at 37 heat units a year. From 1990 to 2016, the warming almost tripled to 99 units. Acceleration in something this dangerous should make the hair at the back of your neck prickle a bit. It does mine.

Ice is melting even faster. Exhibit 5 is a view of a famous glacier valley in Alaska at the same time of year in each picture. It has just vaporized in 63 years.

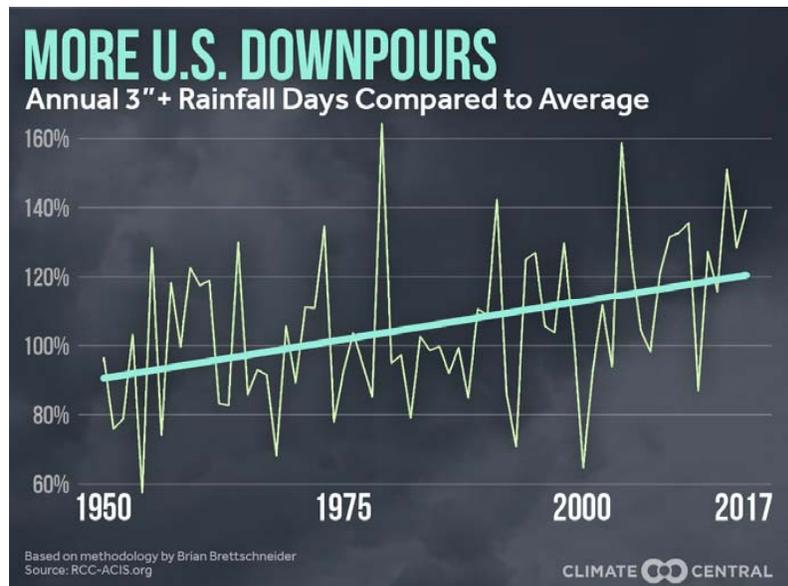
Exhibit 5: Muir Glacier, 1941 and 2004



Source: USGS

The most dependable effect of climate change, as I mentioned, is downpours. Exhibit 6 shows the annual number of three inches per day downpours in the US.

Exhibit 6: Annual 3"+ Rainfall Days in the US

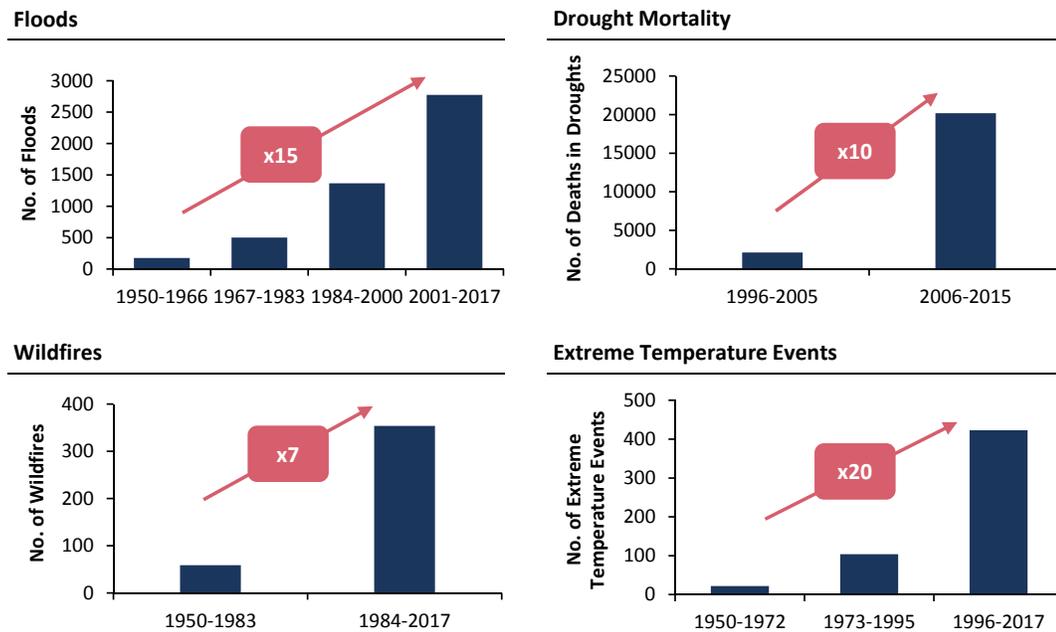


Source: Climate Central

Last year in Houston, Hurricane Harvey dumped 10 inches of rain in a day, followed by 10 inches, followed by 10 inches. If you try to put a probability on that it just does not compute. Perhaps a 1-in-1,000-year event, perhaps almost impossible. It turns out that within the prior 18 months, Houston had already had a 1-in-200-year event. Within 18 months before that, a 50- to a 100-year event. In a terrible update from Japan just this month (July), almost 200 lives were lost and 2 million were asked to evacuate because of a downpour that was so far off the scale that it made Harvey look like a drizzle: 23 inches of rain in 1 single day.

Exhibit 7 is a quick survey of this kind of damage: the number of floods is up by 15 times from 1950, the deaths from droughts up by 10 times, wildfires by 7 times, and extreme temperature events by 20 times.

Exhibit 7: Extreme Weather Events on the Rise



Source: EM-DAT database

Part III: Decarbonizing the Economy

The good news is that greener technologies are also accelerating. This puts me in a very interesting position. I deal with green technologists and they have no idea how bad the situation is for the environment. Then I deal with environmentalists, who I must say are a gloomy lot, and they have no idea how rapidly the science is advancing in this area. Exhibit 8 is a bit dry, but it is absolutely vital. This is from the boss of one of the three largest utility companies in America, not one of our greens. This is a guy from the dark side, you might say, who is just telling it like it is.

Exhibit 8: From the Horse's Mouth

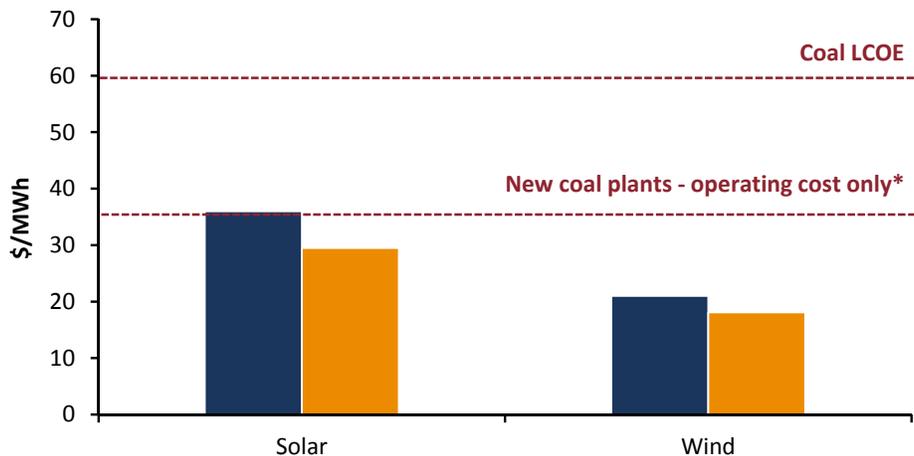
“Without incentives, wind is going to be a \$0.02 or \$0.03 product early in the next decade. Battery storage will be \$0.01 on top of that. And when you look at (...) coal and nuclear, today, operating costs are around \$0.03. New wind and new solar, without incentives and combined with storage, are going to be cheaper than the operating cost of coal and nuclear in the next decade. That is going to totally transform this industry.

— James Robo, 06/22/2017
CEO of NextEra Energy

NextEra Energy controls Florida Power & Light, as well as the world's largest trading unit for wind and solar. So he really should know what he's talking about. And he says that without incentives, wind will be \$0.02 to \$0.03 per kilowatt-hour early in the next decade. Including a few hours of battery storage to carry that power into the evening surge will add another penny. What that means is that wind and solar are going to be cheaper than the operating costs of coal and nuclear, even the best coal and the best nuclear.

Once again: you can receive a gift of a nuclear plant and just the cost of operating it is higher than the cost of building and operating a modern solar plant or a modern wind farm. This economic contest is therefore a done deal. Six months after that comment from Mr. Robo, Xcel Energy in Colorado wanted to close a couple of coal plants early and asked for bids for renewable energy. They were swamped by an amazing 850 bids. The median bid, the one in the middle, below which half were cheaper, was 2.1 cents per kilowatt-hour for wind including storage. The median bids they received for solar and wind power are shown in Exhibit 9.

Exhibit 9: Xcel Energy 2023 Solicitation – Median Levelized Cost per MWh



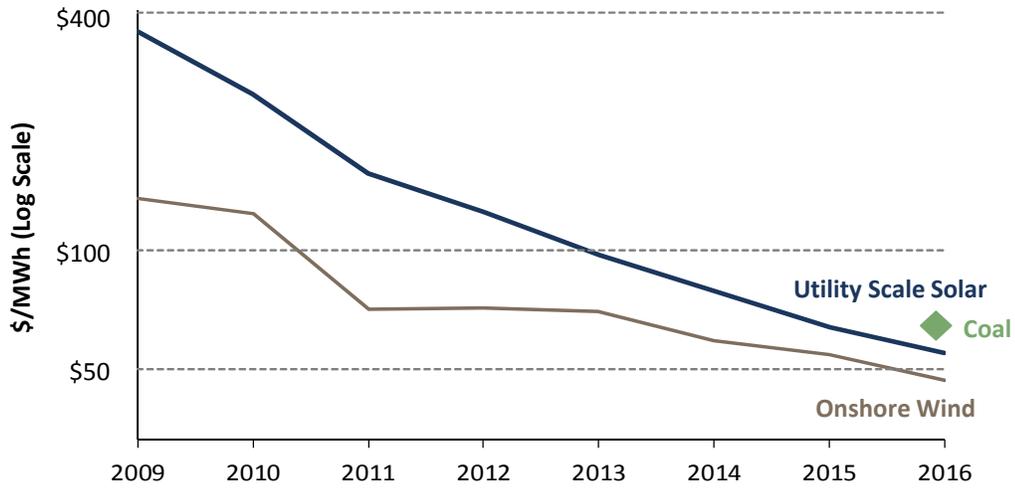
Source: Xcel Energy, Lazard, EIA

*Operating cost for new coal plants includes 30% CCS to comply with EIA New Source Performance Standards

In June, we were all shocked when the Florida Power & Light boss said it would be 2 to 3 cents plus a penny for storage. Six months later, it was 2.1 cents including storage. These bids had median storage costs at only 0.3 cents / kilowatt-hour for wind, and 0.7 for solar, compared to the 1 cent from Mr. Robo's estimate. Even solar, which was unexpectedly dearer than wind, came in at 3.7 cents with storage, which is similar to the operating costs of a new coal plant and well below the levelized cost, including capital, of a coal plant.

Exhibit 10 shows the rate at which wind and solar prices have declined since 2009. Look at that – solar, from \$400/MWh, screaming down to \$55 in 2016 and soon to \$25 or \$30. The median coal plant has been completely outflanked. No one had this even as a gleam in their eye 10 years ago.

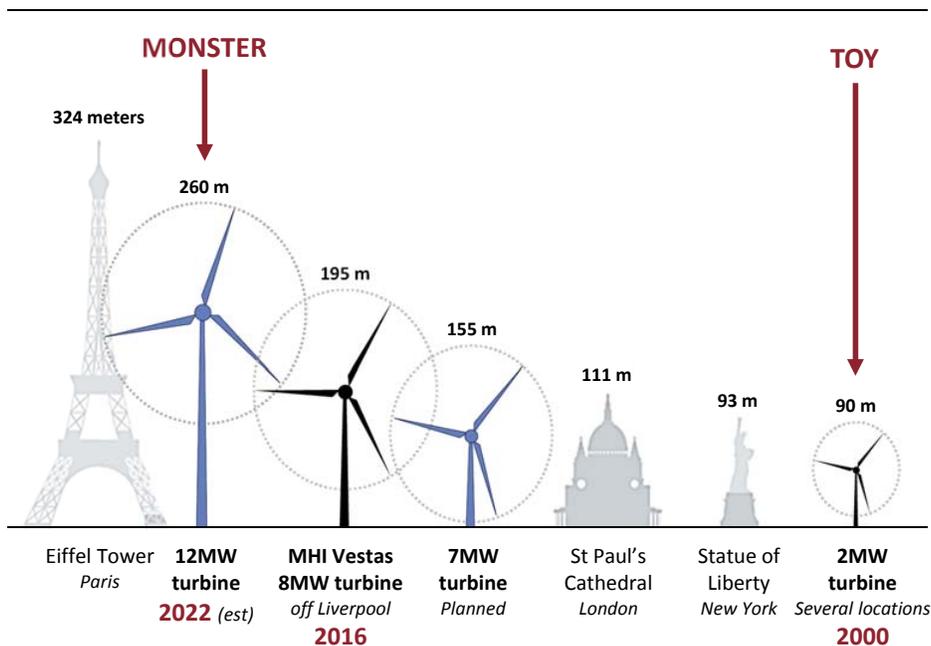
Exhibit 10: Unsubsidized Levelized Cost of Renewable Energy over Time



As of 12/31/16
Source: Lazard

An important word about wind. A two-megawatt wind tower is about the biggest wind tower you will have bumped into in your daily life. If you're cycling through Holland, you will typically see two-megawatt wind towers. That's the size of the Statue of Liberty. In Exhibit 11 I refer to that two-megawatt wind tower as a toy. The real monster is coming: since this exhibit was drawn up, GE actually offered for delivery in 2022 a 12-megawatt wind tower.

Exhibit 11: Giant Wind Turbines Illustrate the Speed of Change



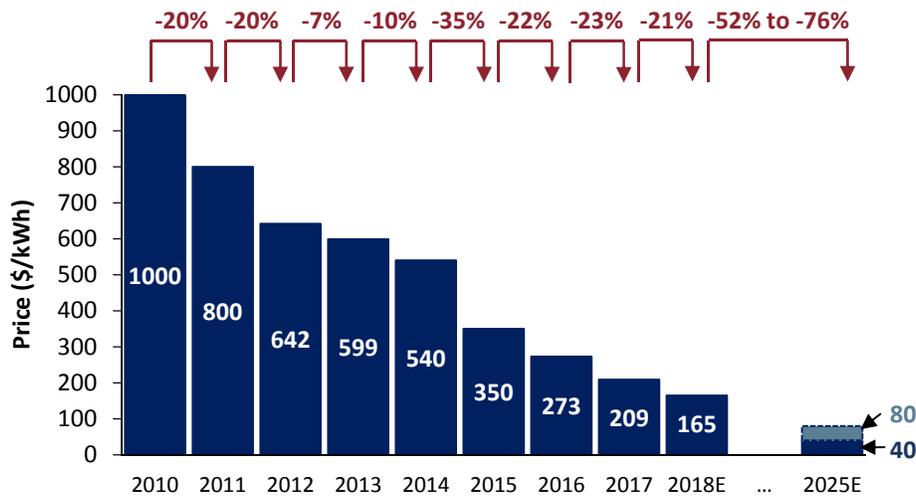
Source: Reuters, GMO

Let me tell you about their 12-megawatt wind tower. It will stand 260 meters, or 284 yards, high. A single blade will measure 107 meters long. On its upswing, the blade would be nearly as high as the Eiffel Tower, where my wife and I had lunch last fall. It is almost impossible to imagine looking across at a wind tower from high up the Eiffel Tower. Let me tell you something else about windmills. The power generated goes up by the swept area, which means Pi R squared. When you take a 10-foot blade and make it 20, you do not get twice as much power, you get 4 times as much. As you go up near the top of the Eiffel Tower, you pick up more wind. Actually, it's a rather disappointing fraction, but you pick up about 20% more wind. But this is the key: the wind factor is cubed. A hurricane with wind speeds of 140 miles per hour does not have a modestly more damaging effect than one at 120. You cube 14 versus cubing 12. It is 60% more powerful. And that is why everyone dreads the 140-miles-per-hour hurricane.

It is the same here – that 20% higher wind speed at the top of the Eiffel Tower will generate 60% more power (less a few percent from mechanical inefficiencies), and the increased length of the blades will be squared. When 20- and 25-megawatt wind towers with new lightweight materials are built in the North Sea and the North Atlantic, possibly in the next 20 or 30 years, they may well generate the cheapest electricity on the planet. (Solar in deserts would likely be an honorable second.)

The disappointing factor for green energy enthusiasts has always been battery costs. Indeed, batteries had been falling in cost for the 20 years prior to 2010 at less than half the rate of progress in solar.⁸ But just as the idea of that disappointment had become a cliché, Exhibit 12 happened.

Exhibit 12: Lithium-ion Battery Pack Prices and Annual Decline



Source: Bloomberg New Energy Finance, GMO
 Low end of 2025 estimate range, at \$40/kWh, assumes adoption of next-generation solid-state battery technology.

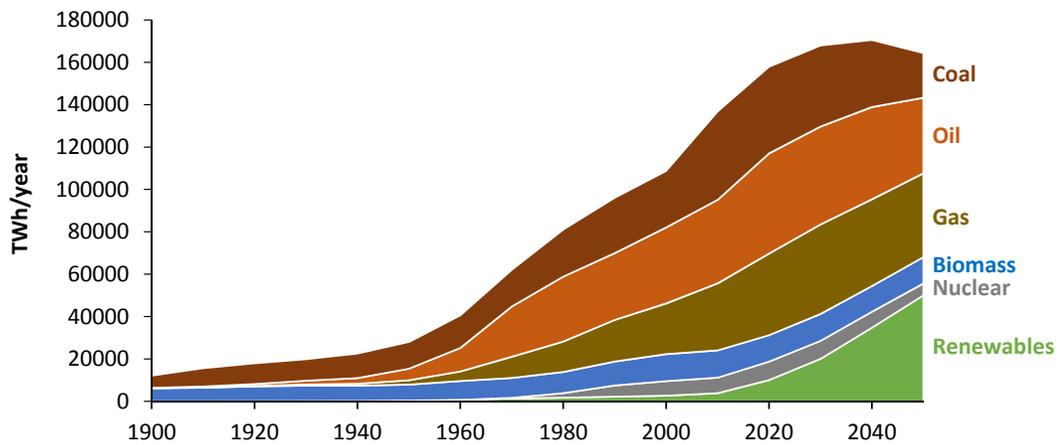
In 2010, Tesla was looking at \$1,000 per kilowatt-hour for battery storage. This year, the insiders say it's down to nearly \$150; we will use \$165. It has dropped 85% in 8 years, faster than solar panels, wind, or anything else. Quite remarkable. This, though, is not the end of the game. When we're building 30 million electric cars globally, engineering and sheer scale will very likely cut the \$165 in half to \$80-odd by 2025 for current lithium ion batteries. When the next generation of solid-state battery technology is introduced, it will likely halve again.

⁸ N. Kittner, F. Lill, and D.M. Kamen, "Energy storage deployment and innovation for the clean energy transition," *Nature Energy*, July 2017.

I'm very pleased to say the Grantham Foundation is investing in a solid-state lithium-ion cell, which was delivered for testing to a major European car factory two months ago. It is half the weight, half the volume, half the materials, and, at scale, potentially half the price. It does not burst into flame, and it charges in five minutes. If we don't get there first, there is a hotshot group at Tufts and another at MIT (go Boston, by the way) who are closing in, claiming similar properties for their new batteries. In addition, Mr. Dyson of hand dryer and vacuum cleaner fame, is also making progress – or at least investing heavily – on this in the UK. Solid-state will happen. It is only a question of whether we save a year or two in development time. Solid-state batteries will make electric cars much cheaper to build than gasoline-driven ones, and they are today already much cheaper to run and maintain with only 15% of the moving parts of an internal combustion vehicle. Rapid charging will also largely remove range anxiety, with electric charging being similar to filling up at a gas station.

So, you take all this optimism, all this progress in green technology, and where does it get us? Regrettably, it only gets us to Exhibit 13.

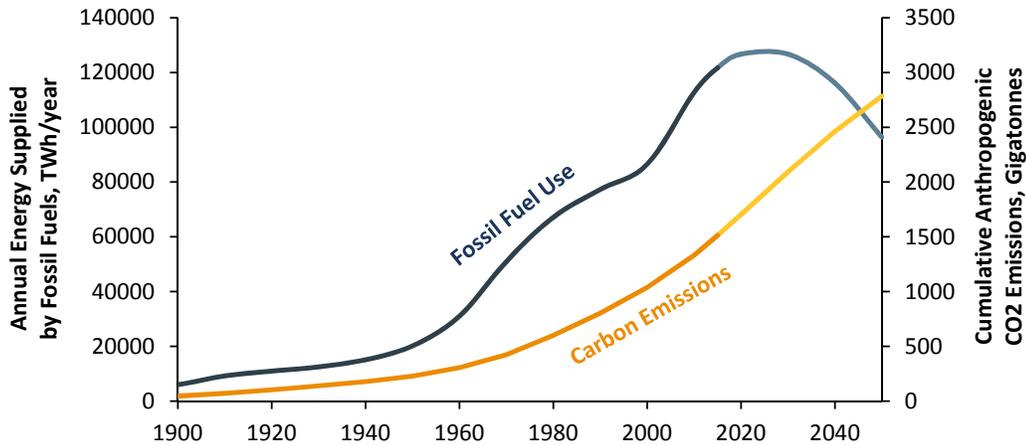
Exhibit 13: World Annual Primary Energy Consumption by Source, 1900-2050



As of 9/30/17
 Source: OurWorldinData.org, Vaclav Smil, GMO
 Data from 2015-2050 is estimated or forecast.

The bad news is that although the renewables in green are surging, by 2050 over 50% of energy consumption is projected to still be driven by fossil fuels. What that means is even if fossil fuels were to peak in a couple of years, and I believe they certainly will peak by 2030 or 2035, the carbon dioxide in the atmosphere will continue to rise and rise. Climate change will not have been stopped. It will barely be slowing down, as shown in Exhibit 14. Bear in mind that the year with the single largest increase in CO2 levels was last year!

Exhibit 14: Annual Energy Supplied by Fossil Fuels, and Cumulative CO2 Emissions

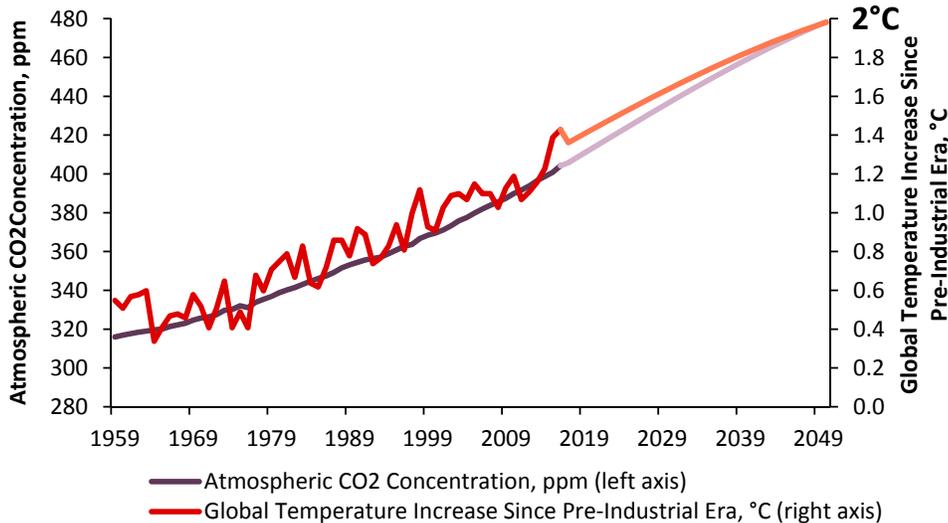


As of 9/30/17

Source: OurWorldinData.org, Vaclav Smil, Carbon Dioxide Information Analysis Centre, GMO
Data from 2015-2050 is estimated or forecast.

This guarantees that we have no hope of limiting the world's temperature increase to 1.5°C. In all probability we will reach our 2°C target by 2050, and we will be fighting tooth and nail – with any luck, with carbon taxes and an improved attitude – to keep it below 3°C by 2100. We really will need luck, in technology and above all in political leadership: the need to stand up to the influence of the fossil fuel industry and manage the widely held dislike of the necessary regulations. The outlook for the world temperature to 2050, even in this optimistic scenario with accelerating progress in renewable energy and green technology, is shown in Exhibit 15.

Exhibit 15: Atmospheric CO2 and Temperature Increase since Pre-Industrial Era

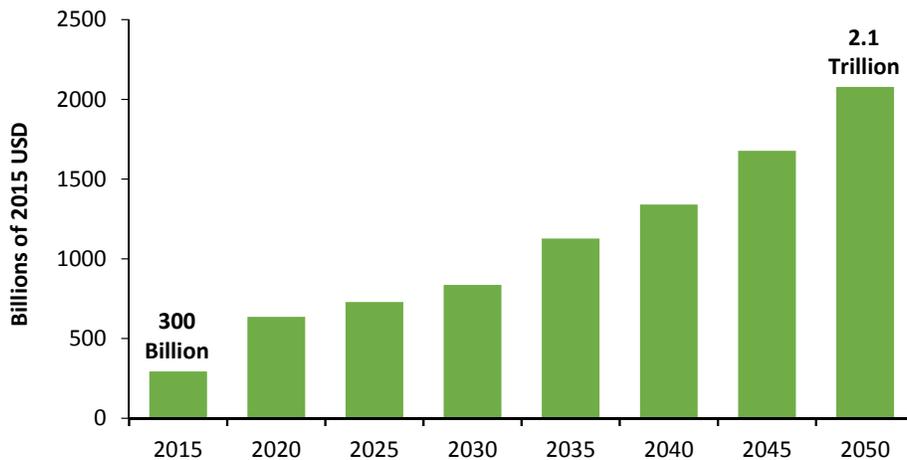


As of 9/30/17

Source: National Oceanic and Atmospheric Administration, GMO
Data from 2016-2050 is estimated or forecast.

The necessary investment in decarbonizing the economy will be epic and is already well over \$300 billion a year. That's the amount of money the world is spending annually to build out renewable energy. To put that in very relevant perspective, \$300 billion is less than the amount of losses in the United States alone from weather and climate disasters in the single year of 2017: Hurricane Harvey, Hurricane Maria, wildfires, and so on, all exacerbated by climate change. Exhibit 16 shows forecast annual global renewable energy capex out to 2050. We will need, by 2050, \$2 trillion per year in today's money, to put in the transmission lines, the power plants, the storage facilities, the reengineered steel and cement factories, and everything else that is needed to completely decarbonize our society. Decarbonizing the economy is arguably the most important industrial change since the wholesale introduction of oil in the early 20th century.

Exhibit 16: Annual Global Renewable Energy Capex

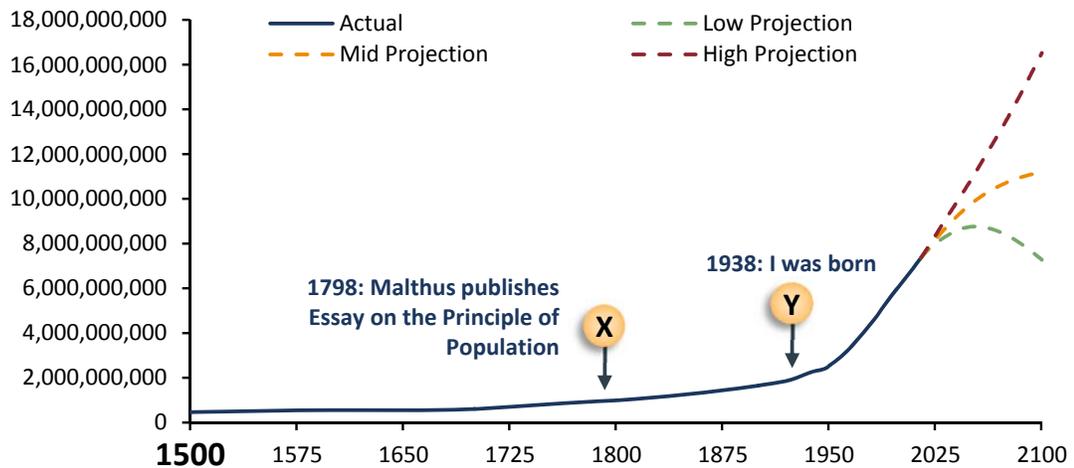


As of 9/30/17
 Source: DNV GL
 Data from 2015-2050 is estimated or forecast.

Part IV: Climate Change and Feeding the 11.2 Billion

So far we have at least had a balance between good technological surprises and the disheartening acceleration of climate damage. It is time now for the terrible news. Sorry about this. I tell you, it's hard to live with for me, too. The issue is food sufficiency. Population growth and increasing wealth are driving up food demand, while climate change, soil erosion, and many other factors are impacting food supply. Exhibit 17 shows what the world population looks like since 1500. For the first few hundred years, it was stable. When Malthus wrote, it was only one billion. When I was born, it was up to about 2.3 billion. Today, just in my lifetime, the global population has tripled. (Whenever you see an exponential chart like this in investing, you know what to do: go short.)

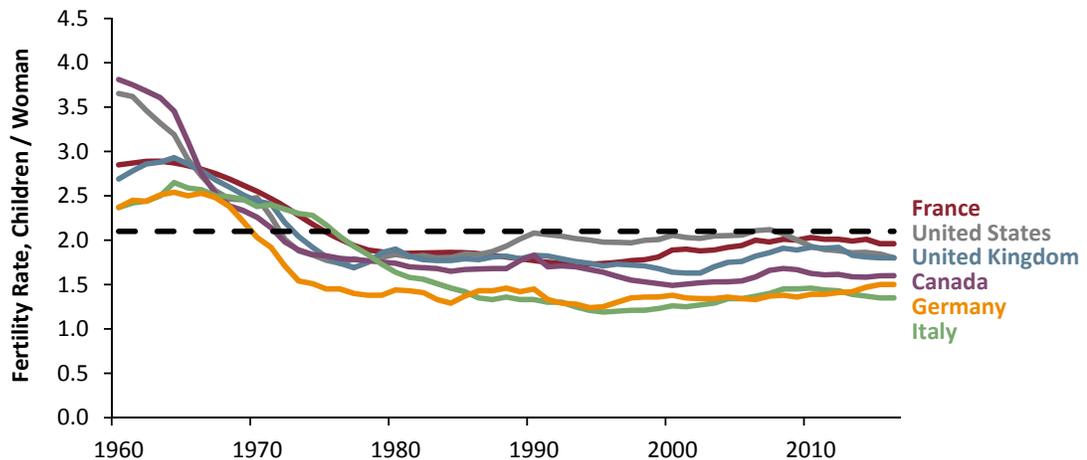
Exhibit 17: World Population and Projections to 2100



As of 1/25/18
Source: UN World Population Prospects

The good news that Malthus never dreamt about, our last best hope really, is declining fertility. In developed countries we're all below replacement level, shown by the black dotted line across Exhibit 18. The irony here is it's probably because we've discovered how incredibly expensive and inconvenient children are. This is my scientific reason. There are other more serious reasons, which we'll get to, including waiting longer to have children and a side effect of toxicity.

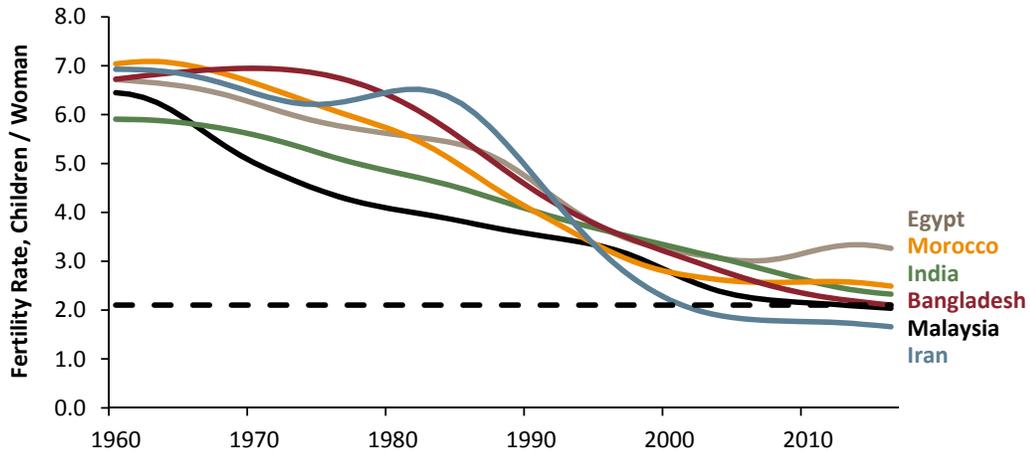
Exhibit 18: Fertility Rates in the "Western World"



As of 12/31/17
Source: World Bank

Fertility rates are dropping fast for many poorer countries too, as seen in Exhibit 19. Iran is my hero. It used to have seven children for each woman in 1960, and now it's down to 1.6. My other hero is Bangladesh, dirt-poor then and now – unlike Iran, this country has no oil. It also had seven children, but today that number has dropped to 2.2.

Exhibit 19: Fertility Rates Decline in Emerging Countries

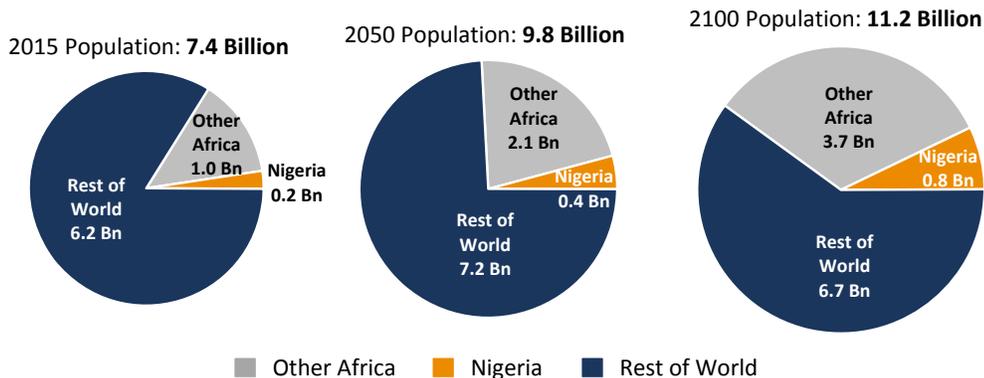


As of 12/31/17
Source: World Bank

It really is amazing. And all they've done is had a persistent program with some education and a little bit of training for the women involved. These women go out into the rural villages over and over again, and try very hard. It really can be done with limited resources and persistence.

Exhibit 20 shows the real problem with population. In a word, Africa, where such persistent policies are sadly lacking. In most of Africa fertility rates are declining, but not rapidly, nor are they forecast to decline rapidly. Indeed, in several countries rapid population growth seems to be encouraged either overtly or by inference – the obvious lack of governmental interest in reducing it. The exhibit shows the midrange world population forecasts from the UN. The rest of the world, in dark blue, goes from 6.2 billion today up to 7.2 in 2050 and then peaks out and drops back to 6.7 by 2100. The rest of the world is not the problem. Given a couple of hundred more years, that 6.7 may fall back down to 2. A fertility rate of 1.6, which is above Japan today, would take the whole rest of the world back to 2 billion in a few generations (six or seven generations would do it, about 200 years).

Exhibit 20: World Population to 2100 – Medium UN Estimate

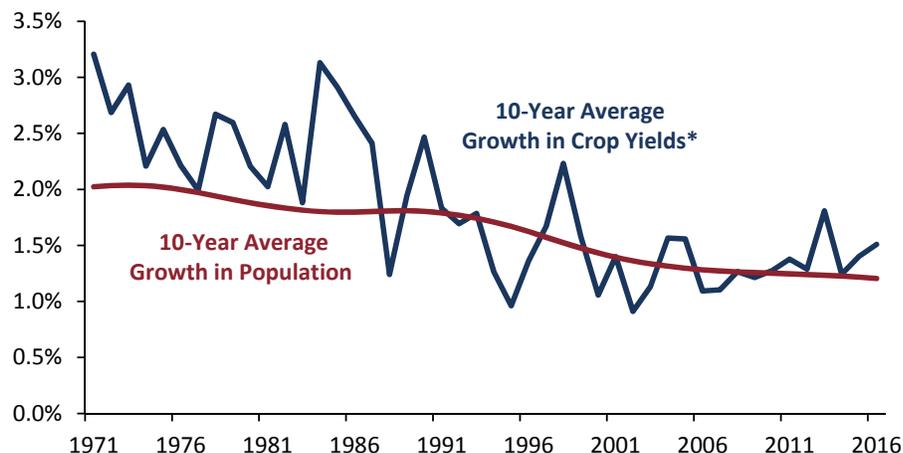


As of 9/30/17
Source: UN World Population Prospects

The problem, as you can see clearly, is Africa. Nigeria, the biggest country in Africa by population, is a perfect case. When I was born, there were 28 million Nigerians. Today, there are about 190 million: the precise number is not known. The midrange forecast for 2100 is 780 million! In recent surveys Nigerians say that seven children is the desired family size, so they are disappointed by their actual six.⁹ Only 15% use contraception and 54% consider it immoral.¹⁰ In a recent poll, 74% of Nigerians said they would love to emigrate if they could, and 38% said they actually plan to try to emigrate in the next 5 years, mostly to the US or Europe.¹¹ 38% of 780 million – that’s 300 million who would love to go to the US and Europe, particularly the UK, which today can feed just half of its current 66 million people – the rest of its food is imported. (The only worse country is Japan, which feeds one-third. Everyone says how economically ludicrous it is for Japan to accept a declining population, but come serious, global food troubles, and they will come, the only way for Japan to even approach internal food sufficiency is to have a much smaller population.) Nigeria is just an example; the rest of Africa is forecast to nearly quadruple its population, or try to, to 3.7 billion people by 2100. When the UN makes these forecasts, we tend to assume they are on top of agricultural issues, but based on their conclusions I strongly doubt it. Another major problem is the sensitivity of the population issue. Not nearly enough time and thought and money is spent on population growth because it’s so politically sensitive.

To get to the heart of the food problem, grain productivity, shown in Exhibit 21, is now barely keeping up with population. There is no safety margin. In the Green Revolution it was growing at 3.5% per year, and now on average since 1995 it’s come down to about 1.2%, with the world’s population growth also at 1.2%. A dead heat. We are producing as much grain as we produce people. There is simply no room for them to eat meat that takes 8 or 10 times the grain per calorie as eating bread directly. And yet, they intend to. This is going to be a very uncomfortable situation for the poor people who can’t afford to buy grain. (The population curve is, unsurprisingly, much less volatile than grain productivity, which is still influenced by the natural vagaries of annual weather. After three years of terrible grain-growing weather, we have had four excellent years through last season.)

Exhibit 21: Grain Productivity and Population Growth: No Safety Margin!



As of 12/31/17

Source: Food and Agriculture Organization of the United Nations, GMO

*For world’s three major staple crops: wheat, rice, and corn

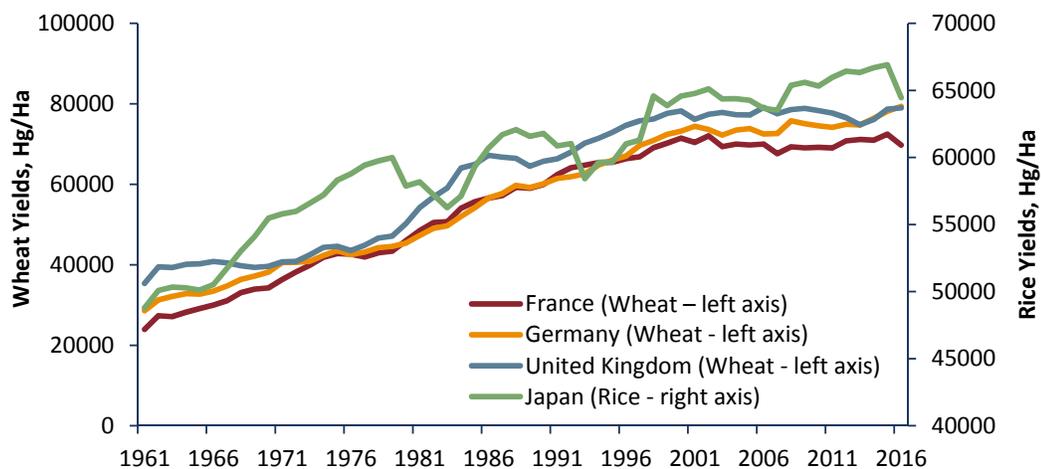
⁹ National Demographic and Health Survey, Nigeria National Population Commission and ICF International, 2014; World Bank.

¹⁰ Pew Research Center, Spring 2013 Global Attitudes Survey.

¹¹ Pew Research Center, Spring 2017 Global Attitudes Survey.

Part of this grain productivity problem is the inconvenient fact that as we progress in productivity we increasingly face diminishing returns. Every species has its limits. Humans will never be 12 feet tall. Let me point out they've been breeding race horses for thousands of years – the chief of the tribe always wanted to have the fastest horse – and they're still breeding them today. Yet Secretariat still has the record for one and a half miles on dirt. Horses haven't gotten materially faster for 45 years and they were barely getting faster for years before that. You can't get blood out of a stone. You can get the horses to break more legs, but you can't get them to run much faster because they are already close to their limit. Now grain, too, has diminishing returns. When looking for diminishing returns, go to the best grain producers on the planet per acre. (Not the US. The US is the best per person, say, a 62-year-old farmer and his son and 6,000 acres.) If you want the best per acre, you go to rice in Japan and wheat in Germany, France, and the UK, as shown in Exhibit 22. Their grain yields were growing brilliantly forever – until the last 20 years, when their progress became very slow and erratic. It is what you expect. And in the US, the USDA's data on multi-factor productivity shows little or no gain from corn in the last 12 years.

Exhibit 22: 5-Year Moving Average of Crop Yields in Leading Countries



As of 12/31/17

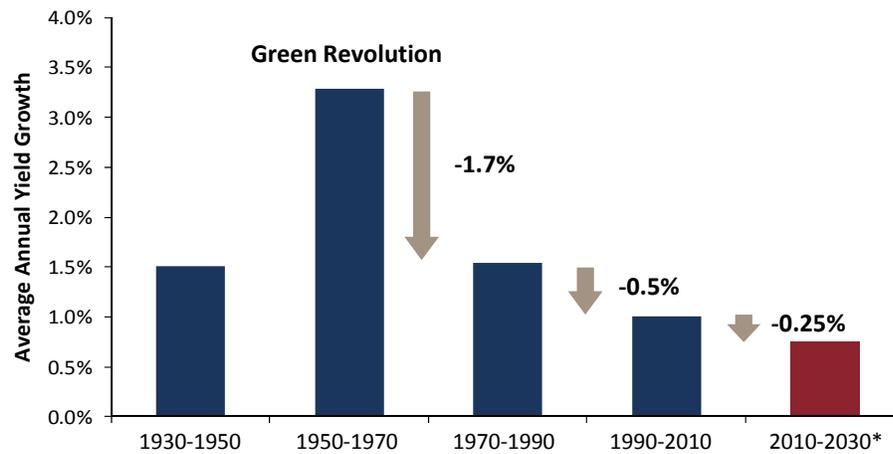
Source: Food and Agriculture Organization of the United Nations

One of the reasons for this is that increased fertilizer use, the backbone of the Green Revolution, is also peaking out. You can use more in poor parts of the world, but the US and China, the two biggest users, already officially use too much – so much, it begins to be counter-productive as well as damaging to the health of waterways from excessive run-off of phosphorus and nitrogen.

Exhibit 23 summarizes all of this, showing the growth in agricultural productivity in the US all the way back to 1930. Back then we were chugging along at a nice 1.5% a year. In the Green Revolution of the 50s and 60s, we accelerated for 20 years to 3.5% a year. Quite remarkable – every 3 years there was a 10% increase in the amount of crops grown on the same land. After that, not surprisingly, productivity growth dropped back then started to drop to new modern lows. Our 2010-2030 estimate, based on talking to scientists, is that productivity per acre would still continue to grow, other things being even, but at a slowly diminishing rate as we approach limits.

Exhibit 23: Diminishing Returns for Grain Productivity

Average Annual Agricultural Productivity Growth in the United States, by 20-year block
Average of yield growth for corn, wheat, and rice



As of 1/31/18

Source: USDA NASS

*GMO projection excluding future effects of erosion and climate change

It turns out, however, that in the future of grain growing, other things will not be even. We face two increasing problems that seem likely to push productivity backwards: soil erosion and climate change. As we dug into these two problems, we quickly discovered a third: the giant seams that can run between different branches of science. Starting with erosion, we spoke to several soil scientists who specialized in erosion who were not aware that future climate change would materially affect erosion even though, as previously mentioned, the single most dependable feature of climate change is an increase in the very heavy downpours that do almost all the erosion damage – with 5- to 10-foot gullies sometimes appearing overnight in the great storms in Iowa and Kansas. Exhibit 24 shows the damage that more routine heavy rains can cause.

Exhibit 24: Gully Erosion



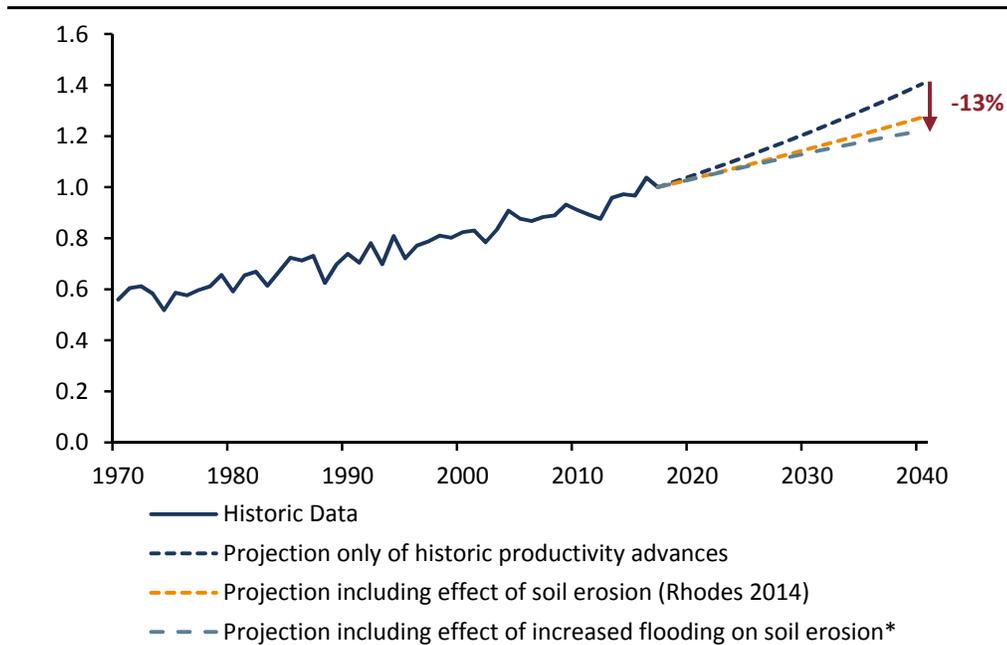
Source: Katharina Helming, CC BY-SA 1.0, <https://commons.wikimedia.org/w/index.php?curid=42387941>

Exhibit 25 shows the effect of erosion on grain production going forward, according to the latest science. And what we did here is make a very, very modest assumption that the 10% damage to productivity that the erosion experts calculated we would get over the next few decades would increase to 13% because of the increase in heavy downpours. (We estimated this ourselves because, at least as far as we could find, no one else was doing it.)

Exhibit 25: Effect of Erosion on Grain Production

US Grain Yields, Historical and Projected

Index averaging corn, wheat, soy, and rice yields, 2017 = 1



As of 4/30/18

Source: USDA NASS; "Soil Erosion, Climate Change and Global Food Security: Challenges and Strategies," Rhodes, Science Progress, 2014, GMO

*GMO estimate

Exhibit 26 is one of my horror show graphics actually. Pictured is an installation describing the topsoil of a particular farming county in Iowa. In 1850, this county had 14 inches of wonderful Midwestern topsoil. Ideally, you need only 4 inches and 3 will get you by. Fourteen inches is a luxury beyond belief for the rest of the world. But by 1900, it was 11.5"; by 1950, 9.5"; by 1975, 7"; by 2000, 5.5".

Exhibit 26: Soil Depth in Iowa Has Halved Since Intensive Cultivation Began



Source: Iowa Public Radio, "The Greatest Story Never Told," installation in Adair County, Iowa, by David B. Dahlquist and RDG Planning & Design

At considerable difficulty, we found the experts on soil in Iowa responsible for the data in this exhibit. We called them and asked what the number was for 2017. And they said, "Yes, erosion is recognized now as a major problem. People are trying much harder; the rate of erosion has come down by a lot, by nearly half." But now, it's 4.8". Just think about that: 14" down to 4.8". Our safety margin has gone from 11 inches to 1 or 2 inches. Yet there are still no signs of panic that reach the public or, apparently, the politicians. That may not scare you, but it certainly scares me.

Now, we get to another disheartening finding from the last 12 months. This is a report from the journal *Proceedings of the National Academy of Sciences*. When you get bad news, you don't want it to come from one of the most prestigious scientific journals. This was a study done by a large team of a dozen or so top scientists, as usual for important studies these days, led by Dr. Liang. As I understand it, they studied what effect actual downpours, droughts, and increasing temperatures had on agricultural productivity in America over the last 50 years and they calculated the effect by each specific grain in each specific area. They put all that data into their model so that they captured the increasing incidence of floods and droughts from climate change. They then extrapolated the midrange of climate models into the future, building in the expected increases in heavy floods and severe droughts out to 2040, where the temperature increases also begin to really hurt (having had little effect up to now, with some areas gaining and some losing from temperature). They concluded

Although all the soil used for agriculture in the US is privately owned, it is in a real sense – an existential sense – a commons like the air and water, for without it none of us survive. We soil owners are all completely free to destroy our common good. Or as two former US Presidents put it:

"While the farmer holds the title to the land, actually it belongs to all the people because civilization itself rests upon the soil." – Thomas Jefferson

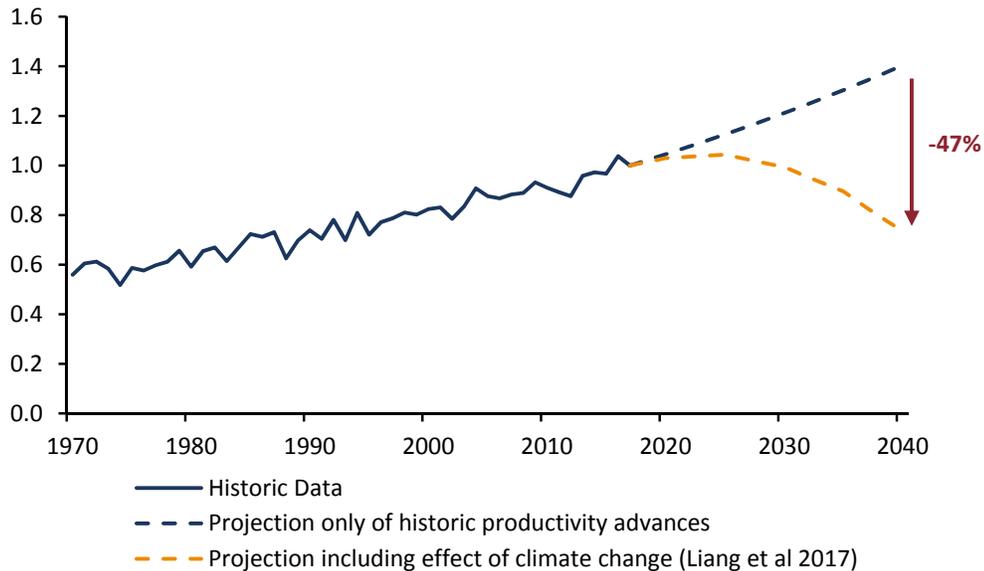
"The nation that destroys its soil destroys itself." – F.D. Roosevelt

that by 2040, if nothing else changed, the impact of climate change would be to take grain productivity all the way back to where it was in 1980, which is Exhibit 27. If this is true, it is incredibly bad news. This is the kind of data where your best hope is that the scientists have made a major error.

Exhibit 27: Effect of Climate Change on Grain Production

US Grain Yields, Historical and Projected

Index averaging corn, wheat, soy, and rice yields, 2017 = 1



As of 4/30/18

Source: USDA NASS; "Determining Climate Effects on US Total Agricultural Productivity", Liang et al, Proceedings of the National Academy of Sciences, GMO

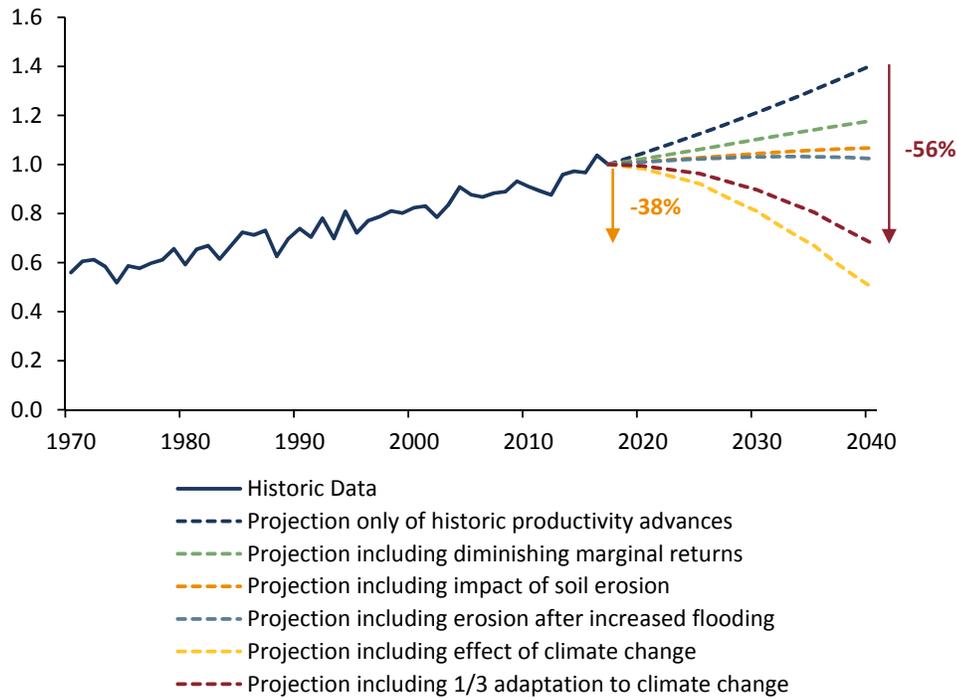
When we called Dr. Liang to ask him some questions, he seemed unaware that erosion had any important impact on the future of agriculture. It does seem to be a problem: climate scientists like him in one box and erosion scientists, with mud on their boots, in another, with very little communication or attempt to coordinate. It is a problem for most specialists – and one we can sympathize with – that to be on top of their fields they have to have a very tight focus. So the scary thing is that our crude attempt to put all these factors together is the first that you, dear reader, have ever seen!

Exhibit 28 is, therefore, distinctly homemade. The lines show the various projections including all these factors one-by-one. At the top is the simple extrapolation of the historic productivity gains. The next line down shows what happens when you build in the diminishing marginal returns that we have seen in Japan, Germany, France, and the UK. Next is the effect of erosion, and the effect of more erosion from increased downpours. Then there's the coup de grace from the climate change study.

Exhibit 28: Combined Effect of Climate Change and Soil Erosion

US Grain Yields, Historical and Projected

Index averaging corn, wheat, soy, and rice yields, 2017 = 1



As of 4/30/18

Source: USDA NASS, Rhodes 2014, Liang et al 2017, GMO

We decided to give a one-third credit for adaptation to climate change: that farmers will be clever; they will change the crops they grow; they will work on building in more drought resistance or flood resistance. (By the way, you have to pick. You can't do both drought and flood resistance at the same time.) Even with adaptation, grain productivity will fall a lot. Maybe in real life farmers will excel and deliver a two-thirds credit for adaptation. What we really need here is improved policy, very productive research, and an unusual willingness to change. But unfortunately, even with substantial adaptation, productivity will still be way down from the historic trend and very likely even down from where we are today.

We also have bug and pathogen immunities to consider. Do you know we lose as much of our crop to weeds, bugs, and pathogens

GMOs and Super Weeds

As a semi technical aside, during the last few million years a few plants have stumbled by mutation into much more efficient ways of processing water, sun, and CO2 and produce up to twice the mass of vegetation. They are called C4 and comprise a lowly 3% of all plants but account for around 25% of plant biomass thanks to their efficiency. In agriculture C4 plants include corn and sugar cane that compared to lowly wheat, barley, rice, and other C3 grains, are monsters of productivity. Well the good news is that one day we may torture the C3 grains into having more of the C4 characteristics to positive output effect. It is a difficult job that has been likened in complexity to nuclear fusion. The bad news is that 14 of the 18 most troublesome weeds are now C4 (from 3% in nature to over three-quarters in modern US farming!). The whole point of genetically modified organism research – or 90% of the point – is to produce seeds that can withstand much-increased doses of specific pesticides, most commonly glyphosate. And which weeds do you think are going to better withstand this chemical onslaught, C3 or C4? We have in fact designed a system to produce C4 super weeds that now compete with our lowly C3 crops like wheat and rice. Whoops!

today, as a percentage, as we did in 1945 before we declared chemical war on these organisms?¹² If we pull back from the chemicals now, the bugs and weeds, which have turned into super bugs and super weeds, will eat our lunch, breakfast, and dinner. Had we never done it, we would be losing approximately the same amount as we are now, but saving impressive amounts of money – approximately as much as for feed or fertilizer.

Before we finish on farming, I'd like to touch on the global distribution of phosphate reserves. We cannot grow any living thing without potassium (potash) and phosphorus (phosphate). We mine these elements, which are very, very finite. We dig these essential fertilizers out and we scatter them in excess around our farms because they are cheap (where the heavy rains often carry them off and pollute the streams and rivers and the Gulf). Exhibit 29 is the problem: 75% of all the high-grade phosphorus reserves in the world are in Morocco and Western Sahara (which Morocco controls).

Exhibit 29: Global Distribution of Phosphate Reserves

Annual Production and Reserves (millions of metric tons)		
	Production (2010)	Reserves
Morocco and Western Sahara	26.0	50,000
World	176.0	65,000

As of 12/31/10
Source: USGS

This share of reserves makes OPEC and Saudi Arabia look like absolute pikers, and phosphate is much more important even than oil. Phosphorus, the key ingredient in phosphate, is an element and cannot be made or substituted for. If ISIS takes over Morocco, I give you my second personal guarantee that within a week the military of China or the US or both will have intervened. We simply cannot manage for long under currently configured agriculture without Morocco's reserves – perhaps 35 to 40 years.

This section began with the premise that food sufficiency will prove to be our civilization's greatest future challenge. If the UN population forecast presented in Exhibit 17 actually happens – even if we stay on that flight path for another decade or two – we will be looking at a failing continent, in my opinion, with some of the damage caused by the need to maintain political correctness. The process may well have started already. Five countries, in my view, have failed already in Africa, five more or so are possibly in the process of failing. Food problems there will put incredible pressure on Europe through immigration, and the scale will be far too great for Europe to handle well. I wrote five years ago that the first casualty of this African (and near Eastern) problem would be the liberal traditions of Europe. Well, it happened a whole lot faster than I feared! Just an accumulated couple of million refugees are already providing political propaganda that is empowering right-wing groups everywhere in Europe. Imagine if Europe were to try and take 100 million, and 100 million isn't even a down payment on the billion and a half or so that will want to emigrate if the population keeps growing like this. Europe will need to get its act together and form a joint policy that is as gentle and as firm and as reasonable as it can possibly be. It simply will not be able to take and absorb nearly as many food and climate refugees as would be required to solve the problem. (I am not speaking as someone with fascist tendencies – on income equality for example, I am left of the Scandinavian countries. Sometimes the truth is politically very incorrect indeed.)

¹² M. Yudelman, A. Ratta, and D. Nygaard, "Pest Management and Food Production: Looking to the Future," International Food Policy Research Institute, 1998.

We have a growing population who want to eat meat, diminishing agricultural returns, and worldwide erosion taking 1% a year of the global soil and half a percent of our arable land. Then there is urban expansion, which is nearly always in fertile river plains, taking the best arable land and concreting it over – calculated to be about two and a half million acres a year.¹³ Plus, there are water availability problems from hell that I could spend half an hour on, or an expert could spend a week on. Reservoirs in South Africa, in Morocco, in Spain, in Nevada, are all shrinking, all suffering from the increased heat. We're depleting our aquifers: in heavily irrigated areas such as Las Vegas or the Central Valley of California, well water levels have fallen by hundreds of feet. In China, parts of Beijing are sinking by four inches a year – that's how fast they're pumping out the water.¹⁴ Over half a billion people globally totally depend on underground, very finite aquifers for their water and food.

For all these many reasons, agriculture is the key to our future success or failure. It is also where climate change has its most consequential effects. But, sadly, it is not the only problem:

Part V: Toxicity, Biodiversity, and the Deficiency of Capitalism

Now, we come to the next piece of very bad news: the 75% loss of flying insects. This was from a report done by German insect fanatics, amateurs who love insects.¹⁵ They went out every year to a different selection from 63 forest preserves. They put out the same nets in the same places at the same time of year. They took all the bugs that they caught, and they laid them out and they counted them. Germans are unbeatable at this type of thing! And to everyone's shock and horror, over 27 years there has been more than a 75% decline in the total quantity of flying insects. These are our pollinators. They have just gone missing. Why isn't this a dramatic item in our news? One-third of all the food plants that we eat need pollination, every flower needs a pollinator. What we've done is created a toxic world, which is apparently not conducive to life as we know it.

This toxicity together with climate change and population pressure form an unprecedented threat to biodiversity. We are, as you probably know by now, in the sixth great extinction. The first five were caused by meteorites and by great shifts in the climate caused by the sun. This sixth one is caused by us, the people. And we, too, are part of the biodiversity that is threatened: the last piece of very bad news science has for us (at least in this paper) is that in the developed world there's been over a 50% loss of sperm count. This is from a recent meta-study¹⁶ of almost 200 individual sperm count studies from different parts of the world: it's hard to imagine how they could get the data that badly wrong. Although I hope they have. One Danish study said that healthy young men in Copenhagen today have lower sperm quality than men visiting infertility clinics 70 years ago!¹⁷ In China, coming from way behind us, they have a 25% loss in the last 15 years.¹⁸ And no one is concerned! Will we worry at 75%? How about 87%? This very well may be contributing already to the declining fertility rate of the Western world, along with delayed marriage. (So, oddly, we may face the problem of low fertility in the long term in the developed world while we face the problem of too-high a fertility rate in Africa.)

¹³ Bren d'Amour et al., "Future urban land expansion and implications for global croplands," *Proceedings of the National Academy of Sciences*, August 2017.

¹⁴ M. Chen et al, "Imaging Land Subsidence Induced by Groundwater Extraction in Beijing (China) Using Satellite Radar Interferometry," *Remote Sensing*, 2016, 8(6) 468.

¹⁵ C. Hallmann et al., "More than 75 percent decline over 27 years in total flying insect biomass in protected areas," *PLOS One*, October 2017.

¹⁶ H. Levine et al., "Temporal trends in sperm count: a systematic review and meta-regression analysis," *Human Reproduction Update*, November 2017.

¹⁷ N. Jørgensen et al., "Human semen quality in the new millennium: a prospective cross-sectional population-based study of 4867 men," *BMJ Open*, Volume 2, Issue 4, 2012.

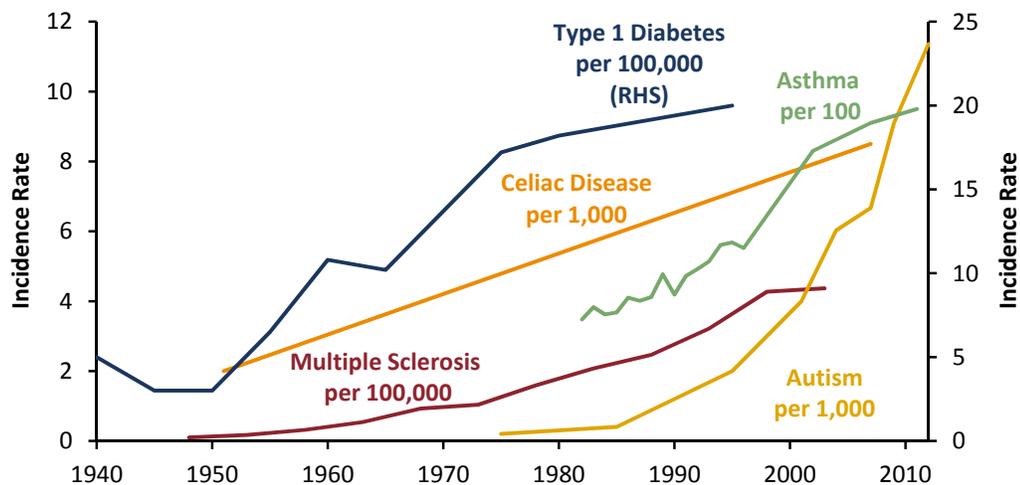
¹⁸ C. Huang et al., "Decline in semen quality among 30,636 young Chinese men from 2001 to 2015," *Fertility and Sterility*, January 2017.

I think toxicity and the chemicals causing it will turn out to be a hotter button than climate change. Climate change is regrettably a bit like the story of boiling the frog in the pot. (Speaking of which, frogs are going extinct too – scientists say the total amphibian population is falling 4% every year.¹⁹) Toxicity, sperm counts, insects going missing, and birds and frogs going with them is something that I think can excite people to action. Europe has turned unexpectedly serious, for example, on the risks of plastics in the last year, banning some single-use plastics. The EU has also banned three incredibly important neonicotinoids that are alleged to kill bees. And very probably do, along with all other flying insects that come near them. This is the problem though: in the EU, if regulators have some doubt, a company must prove its chemical is clean. But in the US, if there's doubt, how could anyone interfere with the capital rights of a chemical company to its chemicals? We will take the side, at least for the next few years, of the chemical companies because there is a lot of doubt. This is a complicated soup we are dealing with – it is hard to impossible to positively prove which chemical is contributing precisely what damage. Have we in the US, inadvertently or otherwise, adopted an ultra-corporate-friendly standard that will produce so toxic an environment before we act that the consequences – totally avoidable on paper – will be extreme?

In any case in the US, the chemical companies will get the benefit of the doubt – not our sperm count, or flying insects, or life in general. At least until we are more obviously on the ropes. An interesting choice to make.

Exhibits 30 and 31 show some of the apparent effects of toxicity. Healthwise in the West, things are going so well in many areas, but autoimmune diseases are just exploding. They have to do with chemicals – endocrine disruptors – in all probability, especially exposure to them during pregnancy. There's the same rise with certain cancers, for which there is no other obvious explanation.

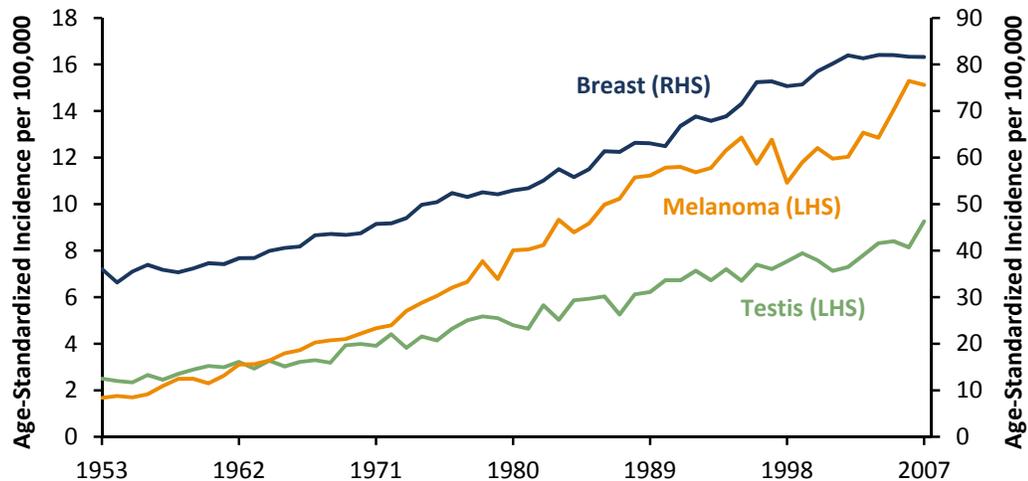
Exhibit 30: Prevalence of Autoimmune Disorders in Western World (1940-2012)



Source: Boström et al 2012, Rubio-Tapia et al 2009, Autism Speaks, National Center for Health Statistics, Gale 2002

¹⁹M.J. Adams et al., "Trends in Amphibian Occupancy in the United States," *PLOS One*, May 2013.

Exhibit 31: Age-Standardized Incidence Rate of Cancers in Scandinavia*



As of December 2007

Source: World Health Organization International Agency for Research on Cancer

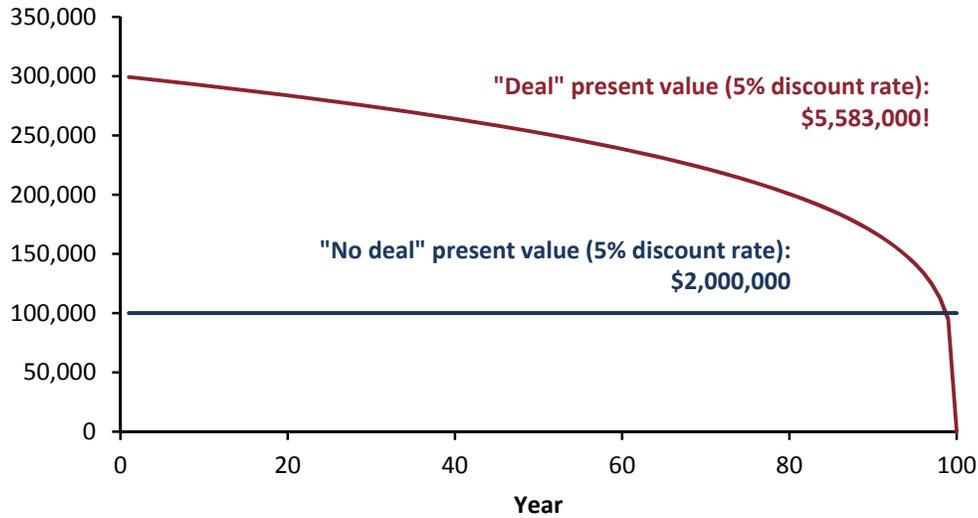
*Average of Denmark, Finland, and Norway. (Countries chosen for having longest available data.)

There's a cheerful professor at Harvard, Dr. Steven Pinker, who's come out with a couple of books saying how wonderful things are. On the data he uses, he's absolutely accurate. Yes, we do live longer. Yes, we have fewer wars, fewer murders, and fewer this and fewer that. But what it doesn't account for is sustainability and toxicity: that we're using up our resources and threatening our biosphere. It's a bit like the guy who falls off the top of the Empire State Building, and as he passes each floor on the way down he is heard to say, "So far, so good." "14 inches of soil, life expectancy increases, so far so good." "12 inches of soil, 8 inches, 4 inches, so far so good." "80% of our sperm count, 50%, so far so good." "80% of our flying insects, 50%, 25%, so far so good." We're simply not accounting for the real underlying damage. Without that accounting, things can indeed be construed as looking pretty good. It's seductive. Right up to the edge of the cliff most of the numbers look better and better and just a few look worse and worse. But how super critical those few worse numbers are.

The greatest deficiency of capitalism is its complete inability to deal with any of these things that we are talking about even though it can handle the millions of more mundane factors that go into producing a workable economy, far better than planned economies. Let me tell you my story once again of the devil and the farmer. The devil goes to a Midwestern farmer and he says, "OK, if you sign this contract and give me your soul, I will triple your profits, your meager profits that have always been a struggle for you. And I will do it for 100 years for you and your descendants." The farmer is desperate, so he signs. The profits are tripled and all is well.

Now footnote 21 of the contract – there are always footnotes with the devil – says the farmer will lose 1% of his soil every year. Because that's what farmers are all losing anyway, big deal. So he signs, and 100 years later there's no soil at all left for his great-great-grandchildren. He has given up soil as well as his soul. Exhibit 32 shows what happened. The expected value of the deal with the devil was \$5.5 million. The no-deal farmer up the road who stuck it out the hard way had a present value of only \$2 million.

Exhibit 32: The Devil's Deal: Your Soil and Your Soul!



Source: GMO

As I've noted before, at least when the starving crowds arrive from Chicago, the farmer dies rich. As currently configured, every MBA ever produced would sign that contract, or fail the course. That is capitalism. Ask Milton Friedman once again. A corporation's responsibility is to maximize profits, not to waste money attempting to guess how to save our soil. There's simply no machinery in today's world, which has gone all Milton Friedman on us, to get this job done: to reach a sustainable agriculture system, and a stable temperature that we can live with – ideally close to the one we have enjoyed for the last few thousand years.

Part VI: Investing and the Environment

Exhibit 33 is our portfolio at GMO of climate change opportunities, which has been around for a year. What we're trying to do is understand, a little ahead of the market, these powerful and complicated new crosswinds as we decarbonize. I hope we are helped in this task by the deliberate propaganda that has been aimed at downplaying the current speed and long-term importance of climate change. Unsurprisingly, the portfolio has lots of clean energy stocks, copper (which is 5 times more heavily used by electric cars than conventional cars), masses of energy efficiency opportunities, and around 20% in agriculture. I can say that I have a very high-confidence belief that these industries collectively will have higher top-line revenue growth than the balance of the economy.

Exhibit 33: Illustrative Climate Change Portfolio (Global Equities)

Segment	Exposure
Clean Energy	39.4%
Solar	9.7%
Wind	8.5%
Other Clean Energy	1.3%
Clean Power Generation	6.1%
Batteries & Storage	14.0%
Smart Grid	6.2%
Copper	8.4%
Energy Efficiency	16.8%
Transportation	6.6%
Buildings	0.4%
Diversified Efficiency	6.0%
Technology	1.9%
Lighting	1.4%
Recycling	0.5%
Agriculture	19.1%
Farming	3.8%
Farm Machinery	1.6%
Timber	0.7%
Eco-Chemicals/Seeds	1.5%
Fertilizer	5.5%
Fish Farming	5.9%
Water	4.4%
Cash	5.6%

Source: GMO

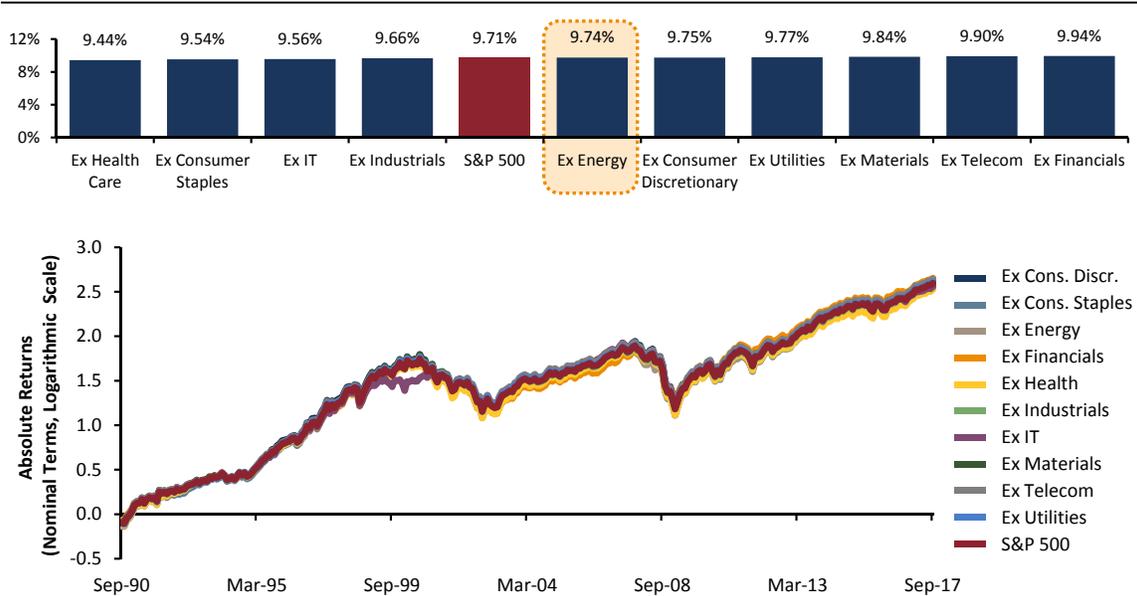
Part VII: The Alleged Perils of Divestment

It should be pretty clear from this discussion that if you're messing around with oil stocks, you're taking the serious risk of ending up with stranded assets, and if you're messing with chemical companies of the toxic kind, you are taking some risks also. Oil companies are being sued everywhere because they've been caught red-handed. They were writing for peer-reviewed journals in the late 1970s, proving that carbon dioxide was dangerous and that the ocean levels would rise. They took advantage of their knowledge: they took it into account to drill in the Arctic and to site their refineries. And they have misrepresented the damage they knew their products would cause. They are vulnerable and face many legal battles as we speak. Yet investment committees, the most conservative groups on the planet as we know – I have spoken to perhaps 3,000 or so of them – maintain that if they divest from oil it will ruin their performance. And that in any case, ethics, à la Friedman, should not come into it. If they accept any constraint at all, they feel, it will ruin their performance. I'm sympathetic up to a point: you don't want everyone with a bee in his bonnet to come marching in. But this issue – climate change – is the mother and father of all exceptions. It is about our survival. Exhibit 34 shows what we did to test this long-held divestment hypothesis. We took out each of the 10 major groups in the market for 30 years, leaving only 9 of the 10 groups in each portfolio, and what we found was

that it didn't make any difference. The entire range from best to worst was only 50 basis points. The return you get without Energy is highlighted – you make 3 bps more without Energy. Look at the graph. Taken together, other than IT in the 2000 bubble, they look like a single series. Even the 2000 deviation settled back as if the bubble had never occurred.

Exhibit 34: You Can Divest from Oil – or Anything Else – Without Consequence

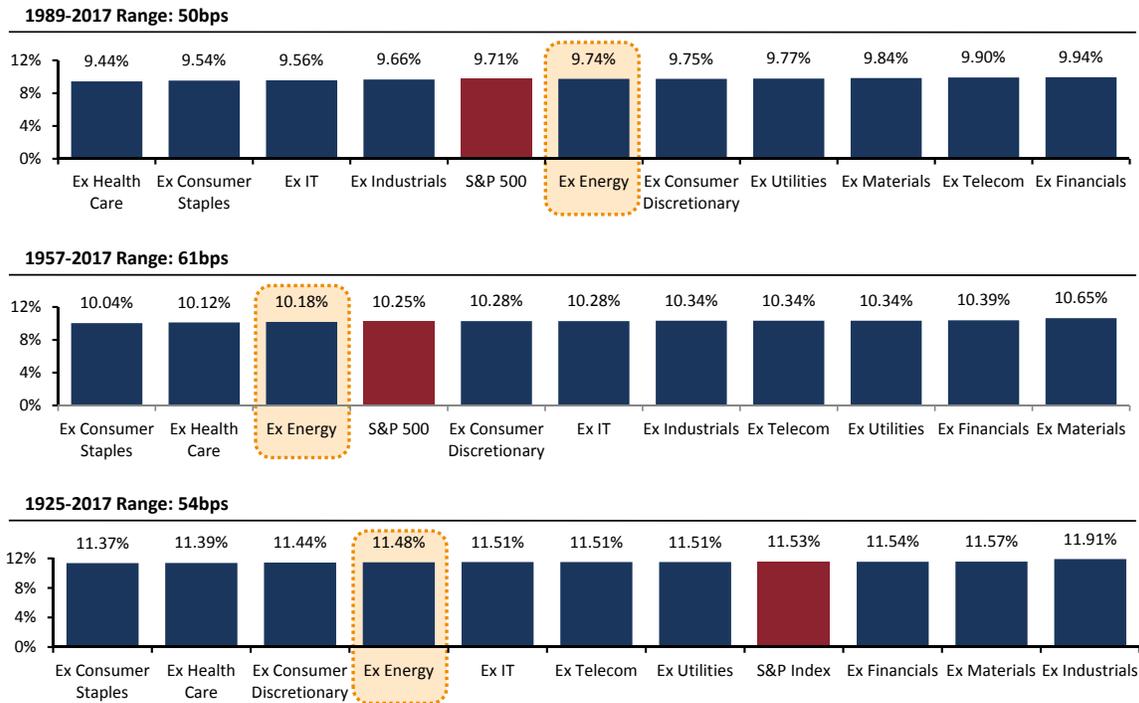
Annualized Absolute Returns (Nominal Terms): 1989-2017 – Range: 50 bps



As of 9/30/17
Source: S&P, GMO

After I first showed this exhibit I had a suspicion that we had picked a lucky time period. My conscience nagged me for a while. So, we went back in history, first to 1957, and then with some considerable effort all the way back to 1925, as shown in Exhibit 35. Look at 1925: the range between missing the best group and the worst has soared from plus or minus 50 basis points to plus or minus 56 basis points. When you divest from oil or chemicals, the starting assumption must be that it will cost you a few tiny basis points of deviation, and it's just as likely to be positive deviation as negative. These are the facts – not the hearsay of investment committees that have managed to maintain an erroneous, but perhaps convenient, consistency over decades on this issue.

Exhibit 35: Divestment Back to 1925



As of 9/30/17
 Source: S&P, GMO
 Prior to March 1957 the S&P 500 is represented by the S&P 90 Index.

There are two quick points to be made before we leave this exhibit. The first is on the power of compounding. In the 92 years since 1925 the S&P 500 would have turned a single dollar – not allowing for inflation and taxes – into \$22,911! Not bad is it? (Without Energy you would have had 4.3% less, or \$21,984.) The second point is to admire how well the market mechanism did this particular job. I have always made a lot of fuss at how incompetent the market mechanism has been in dealing with bubbles, allowing through momentum and career risk for crazy overvaluations followed by dangerous collapses. But here the market has been amazingly efficient at pegging the long-term prospects of these 10 major groups. It has taken away any possible free lunches from buying, say, appealing high-growth technology and selling dopey utilities by pricing technology higher and utilities lower to compensate. Impressive. Who knew? Not me anyway.

Now we can put a more accurate price on divestment and ethics. For example, if you were to consider it unethical to own these oil companies whose scientists wrote, as mentioned, about the serious dangers of climate change in the 1970s only to have management later ignore it all and fund deniers and obfuscators, you can believe the cost of your ethics is about +/- 20 basis points!

There is, however, one more economic argument in favor of divestment: that the Energy sector will be the first example of much more significant mispricing than any sector in the past due to oil companies not bending with the economic winds but fighting them all the way. And why would the market not do its usual remarkable job of forecasting this? Because this is the first time in history, I believe, where a significant chunk of the US investment community does not believe in the most important factor that will affect this sector – climate change. Why? Because we have had a 30-year, well-funded program to make the problem of climate change seem vague, distant, and problematic, the end result of which

is that we have a Republican Party wherein 60% of the people don't believe a word of the facts I have showed you. Some of them, presumably, are in the stock market. How many of these deniers does it take to distort the price? How can this not affect the market's probabilities of carbon taxes, energy regulations, and other important factors? There certainly should be more mispricing than normal and that might just allow for unexpected long-term underperformance of Energy (and perhaps some chemicals). Certainly the governor of the Bank of England, Mark Carney, has been telling everyone that they are bitterly underestimating the future troubles facing the oil industry and I agree.

(The short-term prospect for oil, however, is a very different story and there exists a probability, in my opinion, of a near-term squeeze on oil prices before the electric cars kick in fully.)

Part VIII: What Should Investors Do About Climate Change?

Let me finish this with some recommendations. What I'm hoping you will do, first of all, is vote for green politicians. I don't care what party they belong to. It might surprise you to learn that all the great environmental law of the past 100 years came from Republicans. Second, lobby your investment firms to be a bit greener and encourage them to lean on their portfolio companies to do the same. Push them hard. Cash in some of your career risk units. You will at least be able to look your children in the eye. You may even feel better. And your firms may be able to attract more of the best kind of young recruits who are beginning to care very much more about these issues than we older folk collectively do.

We're racing to protect more than our portfolios from stranded assets and other climate change impact. That I believe is easy enough. But for those portfolio managers who happen to be human, we have a much more important job. We're racing to protect not just our portfolios, not just our grandchildren, but our species. So get to it.

Postscript 1: What Should We All Do?

Of course, the first recommendation is the same: vote for green politicians. Especially support those who are pushing for a carbon tax, or a "cap and trade" program that sets limits for total CO2 production but allows for trading and therefore more directly encourages efficiency and promotes CO2 sequestration – reforestation, improved soil management, and direct CO2 recovery from the air – that in a pure tax would probably be missed. Be aware that a direct carbon tax must be high to change consumer behavior enough to reach our goal of holding to less than 2°C warming – one estimate is \$200-\$300/ton by 2050.²⁰ I would point out, though, that economic sensitivities are much higher for electricity generation than for gasoline. Taxes on gasoline in European countries average over \$300/ton and they certainly have not made London or Paris free of traffic! Nor have these taxes crashed their respective economies. What they have done is created a market for energy-efficient cars that on average get almost twice the miles per gallon as do US vehicles.

In contrast to transportation, \$40/ton is more than enough to get rid of all coal-fired electricity generation in a couple of decades. A ton of coal for generation costs about \$40/ton and generates 2.8 tons of CO2. In addition, as discussed above, the costs of wind and solar plus a few hours' storage are already substantially cheaper. A \$40/ton tax on coal and natural gas would be an enormous incentive to design new generations of larger scale and cheaper storage.

One thing to watch out for is that the major oil companies are all in favor of a modest carbon tax if it comes with immunity to the damage they have caused. That would indeed be a great bargain for them, for they know through their European subsidiaries that gas taxes are simple "pass-throughs." They

²⁰ Environment Canada, 2018.

act as tax collectors and pass on the several dollars per gallon tax immediately to the government. It absolutely does not affect their return on equity.

But should they get immunity? In a world in which we all benefited from using fossil fuels – which we certainly did – and all were ignorant of the damage CO2 caused, there would be no unethical behavior, in my opinion, by oil companies or others, nor any possible breaking of consumer disclosure laws. But this is not the case. The oil companies did know of future damage. Better than all but a handful of scientists. And they deliberately hid this data, as mentioned above, after about 1982, having previously reported it in detail. Worse, they funded propaganda that has delayed our progress on decarbonization, perhaps by several years, and recklessly endangered us. For this part there should be no immunity any more than for any other dangerous activity.

So let us all lobby as best we can for taxes high enough to be effective or equivalent programs that encourage sequestration and give immunity only for behavior that represents ignorance, acted on in good faith.

Other than this main agenda item, what should we do? There are several small household improvements we can make, many of which, like LED lighting, high-efficiency furnaces, washing machines, refrigerators, and insulation, actually save money. At a larger scale, we can buy electric vehicles as their price comes down: the full lifetime costs, including much cheaper maintenance and running costs, are already cheaper for a \$45,000 vehicle and, as mentioned, will be much cheaper yet in the next 10 years. At an even larger scale we can take fewer jet flights and do more video conferencing. One or two fewer flights a year will dwarf all the other savings. But at the highest level of savings of all we should consider having one less child, which is several times more effective than all the above added together as it represents one complete lifetime of carbon footprint plus that person's descendants forever, or at least until we reach a zero net carbon equilibrium. Tough, but true.

Postscript 2: Just Heat Waves or Climate Change?

The current heat wave covers most of the Northern hemisphere so I swelter in Boston along with my sisters in London – who have less air conditioning. But in places as varied as Canada, Greece, India, and Japan it is far more serious as people are dying from the heat directly and the unprecedented fires they cause – including, remarkably, fires inside the Arctic Circle. Of course, global climate is far too complicated for any single incident to be explained with certainty, but these occurrences have in general been predicted for several decades: that we would have more long and dangerous heat waves than normal along with more prolonged heavy downpours. (Pity Japan that had both within a month.) And the accumulating number of new record high temperatures leaves new record lows in the literal dust: as of July 25th, weather stations around the world have reported 122 record highs in the last month, versus only 2 record lows. The hottest overnight minimum temperature ever recorded anywhere – 108.7°F in Quriyat, Oman – was on June 26, 2018. Imagine surviving that without air conditioning! Not only is the base temperature of the planet 1°C or 1.7°F hotter than it used to be, added on to both peaks and troughs, but some climate scientists have predicted²¹ that the flow of weather has been changed so that longer spells of heat and rain should be expected. And both of these are exactly what we have been getting. Outside the US and the UK this new work is discussed and it is taken for granted that climate change is part of it. The discussion is only about which part and how much. Here in the US, as a testimonial to the effectiveness over the years of the denialist propaganda, there is hardly a peep. When people make up their minds based on politics and the clan they belong to, there is perhaps no weather extreme enough to convince them of the obvious.

²¹J.A. Francis and S.J. Vavrus, "Evidence linking Arctic amplification to extreme weather in mid-latitudes," *Geophysical Research Letters*, March 2012.

Thirty years ago the dire predictions of leading climate scientists were laughed at. Now we watch these predictions coming true and ignore the data or pretend to. So, as the world starts to burn up, we twiddle our thumbs and talk about “just another heat wave!” God help us. For we appear incapable of, or are at least unwilling to, help ourselves, and our great scientific skills increasingly appear insufficient on their own.

Jeremy Grantham. Mr. Grantham co-founded GMO in 1977 and is a member of GMO’s Asset Allocation team, serving as the firm’s chief investment strategist. He is a member of the GMO Board of Directors and has also served on the investment boards of several non-profit organizations. Prior to GMO’s founding, Mr. Grantham was co-founder of Batterymarch Financial Management in 1969 where he recommended commercial indexing in 1971, one of several claims to being first. He began his investment career as an economist with Royal Dutch Shell. Mr. Grantham earned his undergraduate degree from the University of Sheffield (U.K.) and an M.B.A. from Harvard Business School. He is a member of the Academy of Arts and Sciences, holds a CBE from the UK and is a recipient of the Carnegie Medal for Philanthropy.

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