Chapter 15

Making It Happen

The world is indisputably warming — probably by another 1–2°C from where we are now. This 1–2°C rise will be painful, especially for the poor, but it does not endanger humanity as a whole. (It is already 6°C warmer than it was 15,000 years ago.) A more dangerous problem is a less likely but not impossible scenario: This more modest 1–2°C rise could set into motion dormant forces that have not been awoken for millions of years and that could in turn cause far larger further temperature increases. In an even more exceedingly unlikely scenario, the short-term domino effects could even be so apocalyptic that they could extinguish our species. (Then again, so could many other unlikely events, too.)

Fossil fuels are almost surely a primary cause of global warming, even if a minority of scientists are still wondering whether it is the only one. Moreover, the harmful health effects of fossil fuels beyond their global warming effects are also highly significant. It is now in the collective interest of humanity to replace fossil fuels with cleaner alternatives more aggressively than ever before. So we end our book with observations about what countries and individuals can realistically do to speed up the worldwide transition to a cleaner planet.

Although we view ourselves as environmentalists, our recommendations are not quite the same as those promulgated by many other better-known environmentalists, such as Greenpeace or the School Strike For Climate (Greta Thunberg's Organization). We have our reasons.

First, we don't have to play to a home audience. We can thus say out loud that environmentalism needs to be not just against but also in favor of

big policies, occasionally even painful ones. Too many environmentalists are simultaneously against everything — fossil fuels, nuclear power, hydroelectric dams, geothermal plants, lithium mining, solar cells, windmills, new electric transmission lines, and tree felling. The requirement of zero environmental harm on every dimension cannot change the world for the better. It only empowers the status quo.

Second, we are more concerned about what policies can maintain large-scale popular support for a long time — not just in rich countries but all over the world. If greener policies turn into expensive vanity projects or greatly hamper the economic development of poor countries, the backlash could delay or even stop them altogether. Plans that allow for regular energy outages or that "go back to nature" are bad plans. Earth cannot sustain 8 billion people without modern industry and agriculture. Even if some environmentalists are prepared to accept the misery consequences of radical energy-use reductions, most people are not. They would revolt and the environmentalists would lose.

Third, we are more concerned about what is realistic and cost-effective and less concerned about what is Utopian and high-minded. The latter makes for good salon conversations but it will not *move the needle*, not now and maybe never. Yes, we too would love countries to spend their military budgets on humanitarian causes instead — but it won't happen.

Fourth, we are focused on initiatives that environmentalists can start today. (There will be more problems in 50 years, but we leave their contemplation to others.) Quoting an old Chinese proverb, we need to begin the journey of a thousand miles with the first steps today. We cannot sit down at the starting line and lament that humanity has not yet gotten far enough or will have to travel a thousand miles (eventually), while billions of people have not even arrived at the stadium. Ideally, we would stop talking and develop (clean) trucks that can drive all of us a thousand miles. Walking may be inspirational, but it won't get us there as fast and as safe as the trucks will.

In this, our final chapter, we describe what governments, organizations, businesses, and individuals can do here and now. Note the order. Global pollution is a big problem and requires big solutions. Countries are as big as effective human organizational structures get.[1] Business, organizations,

[1]However, it is also true that governments, because they are so big, are also often more dysfunctional than many smaller organizations — and sometimes governments are outright

and individuals can play useful roles, but their means are more limited than those of governments. Environmentalists are in a war that can only be fought by large collectives, not by individual heroes — and not just a short but a very long war that will have to be fought for many decades and over many generations

Realistically, all viable prescriptions for *moving the needle* now involve low-hanging fruit. High-hanging fruit is effectively fruitless, because it is unreachable. For the highest-hanging fruit, this is also for the better, because they are indigestible — they cost way too much for the good they do. Unfortunately, indiscriminate activism has endorsed some of them. Fortunately, there are so many examples of better low-hanging fruit that we don't have the space to list them all. This chapter focuses on our favorite ones. Many of them involve the government acting as a catalyst — overcoming bumps rather than climbing mountains. Environmentalism should push for these catalytic actions as soon as possible — ideally, yesterday.

But let's start with where we are today.

malicious. Co-opting government for a purpose is still usually more effective than co-opting just your friends and their friends or even your neighborhood.

1 What Can Countries Do?

We have emphasized the appropriate scales of both problems and solutions throughout our book. The problem is big and the solutions are slow. We explained why even the entire OECD could not stop the growth in world emissions, much less push it down to net zero. The arithmetic does not add up. The majority of emissions are from the 80% of people living in poor countries and their emissions are growing faster than the OECD could ever reduce their own. If you need a reminder, go back to Section 5. **??**.

Furthermore, we have already discussed remedies that are likely to fail (in Chapter 7) and remedies that are likely to succeed (especially in Chapter 8). There are a lot of steps we could take *now*, whatever your broader views and political philosophies are. In the current chapter, we are summarizing our favorite approaches in the hope of leaving an impression. They are not listed strictly in order of importance, effectiveness, or cost. But they are limited to those we consider highly important, highly effective, and relatively cheap. And they are not mutually exclusive. Climate activists, environmentalists, political parties, and governments should work on all of them at the same time.

(1) Increase Innovation

Recall the truck example from the start of this chapter — the one supposed to carry us all to the finish line. The truck is technology. We need to requisition it. Technology does not appear out of the blue. Countries should do everything they can to help develop new clean technologies.

We covered relevant technologies in the third part of our book (Chapters 10-12). Ultimately, technologies that make clean energy *cheaper* are the *only* way to reduce world-wide emissions to the point where atmospheric CO_2 concentration will decline again. Every other environmental measure will, at best, slow the accelerating increase.

➤ Research, Development, Deployment

New technologies require research, development, and deployment (RDD). Research is the part where scientists are poking around and really do not know whether the results will ever be useful. Development is the part where the scientists know that the concept works, but they do not know whether it

can work in the real world. Deployment is the part where companies begin commercialization, with a few first pilot tests in the field. (Engineers call this kind of deployment FOAK, First Of A Kind. The FOAK cost is typically much higher than the NOAK, Next of A Kind, cost.) The borders between the three areas are fluid. For example, the first deployment often uncovers new problems that lead back to new research.

We are not alone. There is near-universal agreement among experts that the best path to green energy adoption worldwide is through innovation (even though these experts may disagree what else should be done). Period. Investment in green innovation is likely to provide the most bang for the buck, much better than green deployment. Lomborg estimates that every dollar spent on fundamental green energy research expects to pay off ten dollars. Although this estimate is on the high end, it is not out of line with other estimates. Even if the expected payoff were only $5, governments should still do a lot more to foster RDD than they do today. And it would be in their own competitive interests, as well. This is the easiest lowest-hanging fruit — increasing the funding for clean-energy RDD.

This is not a socialist proposal. Government research support in the OECD has driven technological development and growth for many decades. Even companies that work without government funding still draw heavily on government-funded basic research (often started at research universities) and on talent educated and trained by schools and universities. The Internet and batteries are just two of many such examples. It's just that our governments do too little of it. Granted, real-world governments have many inherent conflicts and inefficiencies and can easily be corrupted, but even given their shortcomings they should still increase their relevant support and work on doing it a lot better. (And government research support has arguably been focused too much on military than commercial potential. The future of the OECD vs. more autocratic regimes may now depend more on its global competitiveness than its military muscle.)

With such payoffs, recommending more funding for clean-energy RDD is the easy part. Doing it well is the hard part. We need a conceptual framework. How should governments allocate funding? What role should the market play? What are the problems?

➤ Externalities

There are at least two economic externality problems with private RDD, already explained in Chapter 5. The first is that the private rewards for inventions are only a fraction of the social benefits. If RDD is left to private entrepreneurs, there won't be enough of it from a social perspective. The second is the desire of inventors, once successful, to patent their inventions and prevent others from using them. Of course, this is understandable: no one would invest $1 billion in a new battery technology, with its great risk of failure or of the arrival of a superior competitor, if there were not high profits in case of success. But after the technology works, the world would be better off if it were available to everyone at the lowest cost.

Economists do not have universal solutions to these two problems. They do know that the best solutions in the real world are often imperfect mixes of government subsidies and private markets. (Just because markets are not perfect does not make the government perfect. Governments often respond to short-term political pressures and do not seek out the best long-run alternatives.)

Despite the just-mentioned problems, the benefits of clean-energy RDD are so high that the government should fund more of it. The best choices of which technologies to support should be left to panels of expert scientists and engineers. Some far-out alternatives could pay off big, too, and deserve funding. (However, sometimes it does not take an expert to understand that some research is so relatively cheap and could have such positive effects on humanity that it should be subsidized in any event. A few of our favorites are listed in Appendix Section App. A.)

➤ Public-Private Collaboration

Worldwide research funding already largely operates in a mixed public-private partnership way. Governments fund research, often in universities, and the results, if any, are later commercialized by companies. In exchange for generous government subsidies, governments could demand more knowledge-sharing of inventions with other companies.

University researchers and experts tend to be better in assessing basic research than companies. Companies are better at the technology development and deployment stages. At these later stages, the potential profits and losses align much better with corporate incentives. The government may still

want to help with a first "FOAK" plant deployment, but thereafter it becomes high time for governments, researchers, and experts to leave the field to as competitive a market of firms as possible.

➤ Risk and Failure

An important difficulty in funding research is that government employees (and bureaucracies) often have no stomach for embarrassing public failures. Yet the whole purpose of R&D is to venture into the unknown. If we knew a concept worked, we wouldn't need research.

In 2010, the U.S. company Solyndra received hundreds of millions of dollars to manufacture and deploy novel solar cells. It ultimately failed because the prices of raw materials for competing Chinese polysilicon cells dropped too quickly. The resulting fallout made great headlines for the GOP opposition, because Solyndra was funded by the Obama administration. Whether right or wrong, it was Monday-morning quarterbacking. A quarterback who has never thrown an interception on a long pass should probably throw more marginal passes — he has not taken enough risks. If every R&D investment worked out, we would not have made enough of them. We should have aimed higher. And herein lies the problem. Risk-taking is not what politicians and bureaucrats excel in. Ideally, innovation research would be funded by a bipartisan panel.

Failure seems to be more (but also not sufficiently) tolerated in academic research grants, if only because the research results often remain more obscure. This is perhaps one of the reasons why government scientific grants to universities are a good solution.

➤ Prizes and Funding

Traditional research grants to universities are important, but we would recommend some more daring supplemental funding mechanisms, too.

The X-Prize Foundation has offered highly visible prizes that have proved to be great catalysts for creative research. Winners of X-prizes gain not only funding, but also instant publicity and credibility. Elon Musk has now offered a $100 million as a prize for carbon capture. Governments should supplement such prizes. Why can't prizes be $1 billion or $10 billion instead of $100 million?

The government could also offer prizes that consist of guarantees to buy the first product, such as the first 100 GWh of fusion electricity provided

for a price point of $300/Mwh or the first 1 $GtCO_2$ removed via accelerated weathering for a price point of $20/MWh. Would it work? We won't find out unless we try. (The same "fail sometimes" approach is needed here.)

➤ Engineering and Public Education

Finally, a more long-run aspect of R&D is education. This ranges from training more engineers to educating voters and consumers. We need science and engineering to become "sexy" again.

➤ Funding

Our immediate and most important recommendations are also the easiest:

1. Expand the budgets earmarked for green technologies at the National Science Foundation and the Department of Energy — perhaps double, perhaps quadruple. Keep politics out of it and keep it science- , research- , and development-based.
2. Establish large prizes and guarantees for milestone achievements for FOAK plants.

➤ What?

Although we want to restrain in general from too many engineering opinions (except for a few in the appendix), we can't restrain ourselves with respect to energy storage.

Efficient pool-sized energy storage grid battery solutions are the biggest prize there is. If you work for a company that only has a 1-in-a-1000 chance of success, but whose technology could bring down storage cost to half of what it is today, your expected contribution to humanity may be much higher than what a million others could contribute by painful GHG reductions. It is the opposite of the free-riding problem (of curtailing energy use and CO_2 emissions), where you can only be a minor contributor — at best.

If you either want to change the world or become rich (or both), then take your chances here. It's an exciting time.

(2) Share Technology Globally

Most of the RDD funding, and as a result most new discoveries, will probably come from developed countries. Although breakthroughs are more likely to happen when there are many brilliant scientists working together, this is not all good. U.S. universities have been responsible for the largest brain drain in human history, from poor to rich countries — though immigration antipathy in the United States has recently been slowing it down.

Morally, we owe it to poorer countries to help them with their transitions on so many levels. Pragmatically, CO_2 emissions are a global problem. They are as bad when they occur in India as when they occur in Indiana. It is in the world's interest to share technology and expertise. Is it also in countries' self-interests? This is less clear. If we could wave a magic wand or direct global negotiations, our emphasis would be on ways for the world to collaborate more on clean-energy RDD.

How can clean energy be made more accessible to poorer countries? Despite a lot of general waffling and political lip service, most governments have been defending their own industries and not been advocating for the interest of the world, much less the interests of the poor of the world. Public relations talk of *equity* is one thing. Actual sacrifice and sharing are another. There is also a second complication. The best solutions may not be the same in poor countries. In many politically less stable countries, energy technologies need to be different. It makes little sense to build a nuclear plant or a dam in a war zone. Countries without an electric grid may be better off with roof solar cells. And so on.

Our immediate recommendation is therefore for the West, East Asia, and China to establish a joint program that discounts technology license fees or waives patent fees for countries that meet certain poverty criteria and that want to install clean technology domestically. Barge-based near-shore nuclear power plants could provide subsidized electricity to many countries that want clean power but cannot be trusted with nuclear technology.

(3) Tax Local Fossil-Fuel Pollution

We economists love taxes on negative externalities such as pollution. Prices provide incentives to reduce harmful pollution and to develop and deploy alternative sources of energy. Therefore, we would advocate that countries should impose fossil-fuel taxes (instead of today's fossil-fuel subsidies) to reduce local harm; and in reasonable amounts it will also make them better off themselves. Fossil-fuel taxes reduce co-pollution and adverse health consequences and help develop competitive clean-energy export sectors.

Why are we not advocating a major effort for a global CO_2 tax to combat climate change? Forcing 200 other countries to institute global-targeted taxes would be like Sisyphus rolling the proverbial stone up a hill. Even if CO_2 taxes can be passed on behalf of global rather than local interests, they would likely take decades to come into force and not survive some next electoral cycle, recession, or energy crisis in many countries.

In contrast, local CO_2 taxes that provide local benefits are more like putting a wedge under the rolling stone. Such taxes can be catalysts. The government only needs to run the trick one time and get people used to it. Once established, going back to allowing high emissions that make one's own population worse off is going to be more difficult for the fossil-fuel industry — especially, once the public in places like New Delhi and Beijing realizes how much better life can be without asthma and visibility limited to 30 feet.

Nevertheless, let's not kid ourselves: even local CO_2 taxes will be difficult to institute. The biggest hindrances are powerful mining and fossil fuel lobbies, both on behalf of companies and employees. And CO_2 taxes often hurt poorer people more. To institute local CO_2 taxes will require excellent politicians, carrots, and sticks. But locally justified CO_2 taxes and controls stand at least a fighting chance for long-term public support. Globally justified CO_2 taxes do not.

You may disapprove of the modesty of our goal, but we wouldn't be surprised if local CO_2 taxes alone could make a big difference, halving global CO_2 emissions. However, we admit that we have no evidence to back up our assessment. Whereever possible, let's try it out!

anecdote

> Most governments have been deficient in basic tasks. Gratuitous methane leaks from oil&gas wells are low-hanging fruit. Burning off leaking methane would be cheap. However, it remains even cheaper for producers to abandon wells than to appropriately plug them at the end of their lives, and few governments have had the attention bandwidth to do much about it. They should impose harsh penalties. Governments worldwide — especially those in the Middle-East and North America — have been dysfunctional in failing to institute such.

(4) Forestation

In Chapter 12, we explained that the world is still actively deforesting. Nevertheless, there is also a lot of space to plant more trees elsewhere, including in the United States. A lot of today's forests are simply in the wrong locations, places where poor people need their space for planting subsistence crops.

Forestation has a lot of local environmental benefits, it is widely popular on a bipartisan basis, and it is cheap (to the tune of \$10 per tCO_2e). There is no reason for countries not to go ahead immediately with spending more money incentivicing the planting of more trees.

It is important that the plan be to harvest the timber. Wood sequesters the CO_2. It must not be allowed to burn and decay. And harvesting is what makes the enterprise economically viable in the first place.

There are commercial timber companies that could be subsidized if they lay out a sustainable model, in which they receive reduced-cost access to public lands, grow timber, cut them down, but allow wildlife to move to adjacent parcels. Not every environmentalists will be thrilled about such plans, but many will be. It's a sacrifice well worth making.

We can do more yet. There are better and worse ways to plan CO_2 consuming plants. (It may also make sense to work on other CO_2-absorbing plants, but this is not mutually exclusive.) The forestation enterprise could be made more effective and economical with more research. What trees planted where are economically most promising? As we wrote many times, global warming is a problem that needs to coopt economics, not fight it.

(5) Price Electricity By Demand and Supply

We only cut our CO_2 emissions to piss off the utilities company.

Wind and solar are already the cheapest forms of power in history. The problem is electricity storage.

But why do we need so much storage in the first place? Part of the reason is because few of us are used to dirt-cheap electricity from 9am to 5pm and expensive electricity from 5pm to 10pm and 5am to 9am. How many of us would be willing to buy smarter appliances and adjust if we could count on saving half of our electricity bills *and* at the same time do good for the environment? And we could make it twice as expensive for those of us who refuse to adjust. We suspect most of us would learn pretty quickly — and saving money on expensive electricity is something that should appeal even more to countries and people that are poorer.

Governments can help facilitate the switch to demand-sensitive pricing on many levels. They should help electricity companies sign up as many customers as possible to demand-sensitive pricing plans. They should tax fossil-fuel plants to increase their after-hour prices further. They should help make electricity price information ubiquitous. They should open a frequency in the RF spectrum on which providers could broadcast the current and anticipated prices of electricity (the same way we broadcast atomic clock signals and hurricane warnings). They should standardize power-embedded signals and encourage standardized Internet-based two-way signaling of prices and impending customer electricity demands.

Again, our suggestion is for governments not to fight market forces in order to reflect global CO_2 externalities over decades or centuries. Instead, it is for governments to act as one-time catalysts to bring about the changes that switch consumer habits to consuming when energy is both dirt-cheap and no-dirt-clean — and then to get out of the way as soon as possible.

(6) Uproot Environmentally Bad Habits

Many emissions can be cut without spending a penny. But, as Benjamin Franklin noted, old habits die hard. Many people are not only too busy to worry about changing (a status quo bias) but intrinsically distrustful of anyone trying to alter what has worked for them for a long time — even if they barely remember the reasons why they are doing what they are doing in the first place. The good news is that habits can be altered by governments acting as catalysts. Governments can jump-start changes and then get out of the way once habits have changed. Governments won't have to fight this battle forever.

Here are a few important bad habits in the environmental context.

First, most people don't know or don't care about electricity pricing. They have busy lives. They still think of electricity as being *more* expensive during the day rather than the night, which is how it was when coal plants supplied factories with electricity mostly during the day-time. How can we get people to notice and change? If we can get consumers onto time-of-day plans *and* make them aware that electricity is cheap during the day and expensive at night, then we, the people, will probably do all the rest voluntarily.

Second, habits influence agricultural tilling and farming practices (Chapter 11). Turning over the soil reduces weeds and increases yields, but releases more CO_2 than No-Till farming. Worse, farmers tend to be intrinsically even more conservative and distrustful of government than the average person. How can we nudge farmers to adopt practices that will not cost them much and help improve the environment? We could offer them direct subsidies for better tilling practices and tax them for harmful tilling practices. But the big deal will be to change farming habits. Getting farmers to try out an alternative at least once would be winning more than half the battle.

Third, habits can be based on and reinforce mistrust and myopic consumption patterns. The *Energy Efficiency Paradox* is that most people decline to spend more upfront even when the lifetime energy and cost savings are far greater. For example, a majority of people decline to spend more on energy-efficient washing machines, even though they would come out financially better.

Changing habitual behavior patterns is not easy, but it can be done. Here are three possible approaches.

➤ Coercive Mandates

A forceful way to overcome inertia is to mandate the purchase of more efficient devices. The government effectively forced inferior incandescent bulbs, inferior housing insulation (with building codes), and inferior gasoline engines (with MPG standards) off the market. The flip side of this approach would have been to subsidize LED bulbs, insulation material, and more efficient gasoline engines to make them cheaper. (The two could go together, too.)

An important aspect of coercive mandates is that they help the ultimately better solution steal the appropriate economies of scale from the prevailing worse solution. Economists tend to be skeptical of mandates for good reasons. There is a lot of potential for abuse and unintended consequences. Thus, they are probably best used only if the social disadvantages of the current solution are so large that there is little chance that the government could get it wrong.

➤ Nudges

There is often a better, less coercive, and brilliant alternative: Nudges, i.e., gentle prods, courtesy of Richard Thaler (a Nobel-Prize winning economist) and Cass Sunstein.

Nudges are at their most powerful when they can put people's intrinsic inertia to good use by selecting good defaults. In an example, 42,000 households in Germany were asked to choose between a green-energy provider and a fossil-fuel provider for their electricity. The green choice was slightly more expensive. For those households for which the traditional fossil fuel provider was the default, only 7.2% switched to the green alternative. When the green alternative was the default, 69.1% of households chose to stick with it. This was the case even though everyone could choose whatever they wanted.

Thaler and Sunstein also advocate taking advantage of social norms. Many utility companies now include Home Energy Reports in their bills, which tell consumers how their usage compares to that of their neighbors. This tactic has led to remarkably large reductions in energy usage. It can be pushed further in many ways. If someone has switched and saved a lot of money doing so, the government could tell neighbors and friends, or even reward switchers when they themselves tell neighbors and friends. (Some advertisers post rewards for bringing in other customers.)

Nudges can also help overcome an information problem. Why would the government need to tell people that they can save money with better lighting,

insulation, and cars? Are they not smart enough to ask themselves? They may be, but it would be difficult for buyers to compare different products when every seller can measure and claim benefits in their own way. Vendor claims would degenerate into a race to the bottom. In such cases, government can promote better products not by forcing everyone to abandon inferior products, but by disclosing standardized cost estimates. The classic example is the standardized Monroney sticker on cars, which informs shoppers of fuel efficiency. In many cases, information disclosure is cheap for sellers and salient to consumers. Of course, it does not work everywhere. In some cases, too much good intent can lead to uselessness — as everyone who has ever had to sign 120 disclosure documents when obtaining a mortgage can attest.

Nudges can be brilliant and cost next to nothing. It's just that someone more clever than us has to think of them in the first place and then implement them.

➤ Product Introduction

Governments can also help implement beneficial social changes in the same ways that companies try to increase their sales:

Advertising is the most common way to make the public aware of changes.

Price discounts for early adopters of better climate practices make it easier to try out different practices. For a time, governments should subsidize electricity consumption during the day and tax it at night, *beyond* what is otherwise optimal, making cheap daytime electricity even cheaper. It's the same strategy by which Uber weaned us from taxis and alerted us to its presence. Uber rides started out cheap but they no longer are.

Guarantees for those who are willing to adopt new practices can reduce the fear of the unknown unknowns. For instance, there should be strong one-time "no-worse-off" guarantees for all farmers who are willing to try out more environmentally friendly tilling practices.

(7) Reverse Bad Technological Lock-In

There are many cases in which economies suffer from Technological Lock-in. These are situations in which the economy is too committed to an existing technology to allow it to change to a better one. At some point, when the social benefits of a switch become much higher than the one-time transition costs, then governments should step in to make us better off. Here are two examples: lighting and cars.

Just one decade ago, LED light bulbs cost about three to five times as much as incandescent light bulbs. However, their lifetime cost was only one-fifth as high. LED bulbs last longer and consume less energy. Nonetheless, the aforementioned energy efficiency paradox kept most consumers using incandescent bulbs. In turn, this buying pattern maintained economies of scale in incandescent production and reduced economies of scale in LED production.

In 2007, the Bush government banned the manufacture of particularly inefficient household light bulbs.[2] After some detours,[3] the end result is that today's LED bulbs have become cheaper to purchase than incandescent bulbs ever were! Competitive incentives and mass production have worked wonders for per-unit production costs. When incandescent bulbs ruled the market, they had the existing economies of scale on their side. Now LED bulbs have them. Who could argue with the result? Cheaper, better, less polluting!

Take another example. For the longest time, gasoline cars were thought to be irreplaceable. Their production had economies of scale. Yet it has become increasingly clear that electric cars are superior. Combustion cars have served civilization well for a century, but their time has passed. The problem is: How can electric cars overcome the advantages of gasoline cars in terms of mass production, available infrastructure (especially gas stations), and consumer familiarity?

Governments helped. They did not invent electric cars, but they did support relevant fundamental R&D for many years. They also offered generous

[2] We would not have advocated for an outright ban, analogous to an infinite tax, but merely for a much higher tax instead.

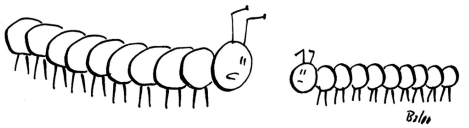
[3] In hindsight, the mandate may have been three years too early, because LED needed a few more years to overcome the advantages of fluorescent bulbs, another technology. However, without the mandate, the development incentives would have been lower and it could have taken a decade.

subsidies to car makers for early zero-emission cars. We all know what happened next. Tesla showed the world that electric cars are not only more efficient and pollution-free but also no more expensive than gasoline cars, courtesy of the economics of mass production and falling battery costs. Soon, electric cars will be cheaper. Every car maker on the planet is now planning to phase out combustion engine cars by the end of this decade.

With the exception of the fossil-fuel industry and combustion-engine makers, everyone has won. Perhaps best of all, having acted as the catalyst that drove the switch from a worse equilibrium to a better one, government is now no longer needed. Its job is done. It can now get out of the business of deciding winners and losers and let market forces take over.

(8) Coordinate Transitions

Technological lockin is especially severe when it comes to problems that require many simultaneous changes. Selling electric cars requires public charging stations. Tesla not only had to invent practical electric cars, but it also had to install a charging network, because there were no electric gas stations. Other car makers are still working on the problem. To build profitable charging stations requires widespread adoption of electric vehicles. A classic chicken-and-egg problem!



Strength and speed are useful, son, but coordination is *crucial*!

Let's zoom out to a wider perspective. There are two coordination problems that are so paramount that they could make or break the transition to a clean energy economy, and only government is in a position to move them along.

The first is the capacity of the electric grid. It has served us well in the past, but it has grown into a messy tangle of poor interconnections dominated by local regulations and interests. Without the ability to connect to a grid that can make good use of clean electricity, it makes little sense to generate more clean electricity. Making it cheap for clean-electricity providers to sell electricity into the grid is of first-order importance and requires national involvement.

The second is the coordination of electricity supply and demand. We need a universal open bidirectional communications protocol for generators, end-consumers, and storage on the electric grid. Establishing a protocol is harder than it appears. It requires addressing issues such as geography (which price matters to what house?), time (what is the price now and what will it likely be?), and cyber-security (how can the grid mitigate wrong and/or malicious signals?).

One example we mentioned earlier that requires coordination is the build out of charging stations in conjunction with the growth of electric vehicles. In a comprehensive article, the Economist states, "Look beyond the glamorous, high-tech filled automobiles and a merciless bottleneck appears. Governments are only waking up to the problem. Put simply: how will all the electric cares get charged? The current number of public chargers - 1.3 million - cannot begin to satisfy the demands of the world's rapidly expanding electric fleet."

Our governments need to tackle both problems.

(9) Reduce Green Red Tape

Real-world governments enact not only useful regulations, but also many bad ones. Many start out good but turn bad over time. Economists consider this examples of unintended consequences.

I kind of regret objecting so strongly to the wind farm they originally had planned

Most of us (especially our lawyers) like the ability to sue parties that harm us, but the law can also become our own worst enemy. Most environmentalists want wind power, just not in their own backyards. The typical wind project in the United States already takes over a decade (!) to get lease approvals and permits. This is one reason why American offshore wind capacity is less than 5% of Europe's.

Yet even in Europe, neighbors don't like rumbling from windmills. Farmers and fishermen often don't like windmills, either. In America, offshore wind opponents are often the wealthy and powerful who live the near the shorelines. But what is the alternative? Yes, someone may deserve consideration even in the case of clean wind power, but year-long lawsuits are not the ideal way to handle the problem.

Most of us environmentalists like clean cars and clean grids. As we explained in Chapter 10, the necessary batteries are made out of cobalt, nickel, and lithium today. Without a lot more of these elements, there will be no clean-energy transition. Yet, few of us environmentalists like mining — but civilization's choice now is between more mining and no energy transition. We can't have our cake and eat it, too. Of course, we should not want unregulated mining—that would also be a terrible idea. However, it now takes 16(!) years to approve the average global mining project (*before* it can start breaking ground). We must make green-related mining decisions better and faster.

anecdote

Nevada has some of the richest Lithium sources in the world. The environmental harm of lithium mines are modest (unlike, say, for lead, gold, or coal mines). Alas, standing in mid 2021, new Lithium mines in Nevada have hit some "minor" snags:

Ioneer Corp wants to build a mine halfway between Reno and Las Vegas. Unfortunately, three years into the process, the U.S. Fish and Wildlife Services discovered a rare plant named Tiehm's buckwheat, and later named it an endangered species.

Lithium Nevada Corp wants to build a 20,000 acre mine in the Thacker Pass. Unfortunately, the Reno-Sparks Indian colony, about 300 miles southeast of the project, has filed a lawsuit based on the National Historic Preservation Act (plus some process violations about environmental approvals). It is where Native Americans in the late 1800s hid and were slaughtered by U.S. soldiers. The relevant area is only half an acre.

The environmental harms may be modest and plausibly resolvable. The economic harms of the law suits are not. They could take years to resolve.

We like safety, fairness, and competitive regulations, but these regulations also prevent new competitors from entering. For example, today only utilities are allowed to buy energy from the grid. You cannot build a wind farm to power a data center if it also needs occasional backup from the grid. Don't ask how difficult it would be for a data center to obtain utility status. (And don't ask how many different agencies and bodies have to approve anything that wants to be connected to the grid or wants to extend the grid.)

We like *extremely* stringent safety regulations for nuclear power, but it seems as if the NRC considers reactors safest when they are not built. It has become impossible in many countries to design and build better and safer plants. The time, effort, and uncertainty to get regulatory approvals have killed off most of the nuclear construction industry over the last five decades.

We are keeping our fingers crossed that Terrapower's new Wyoming plant will be able to overcome the hurdles and build the safest nuclear power plant in the world.

Good regulations are not easy. They require constant struggling. Unfortunately, once in place, even bad rules are difficult to overturn. How many unnecessary stop signs have ever been taken down when traffic patterns changed later? Business as usual has become too slow to deal with the world's climate crisis. The rate of regulatory evaluation and change has to be accelerated when it comes to environmentally better solutions.

➤ Concierge Services

Many regulations make sense by themselves but not when considered in conjunction with hundreds of others. Figuring out how to start a new clean-energy project is only slightly less painful than a root canal. If we want clean energy, we have to try to entice more competition by making it easier. Governments should:

- Guarantee regulatory "concierge" service, an assigned shepherd with expertise in the regulatory and permission processes and good connections to the relevant agencies, who can facilitate much faster reviews by agencies ideally with firm short deadlines and without undue compromises on safety and environmental standards.
- Guarantee and pay for the interconnection of a new entrants' first plant into the electricity grid.
- Guarantee a stated price for a fixed amount of *clean* dispatchable electric energy over the first decade. The specific terms (e.g., time-related pricing) can be revised every five years. They could even be auctioned off.

This model contrasts with the current *modus operandi*, in which the government funds plants, mostly by incumbents who know how to navigate the process and who have placed past and future employees into the key government posts.

(10) Lease Out Land for Solar and Wind

The Federal government owns over a quarter of all the land in the United States, much in sparsely populated states in the West. In Nevada, the government owns 80% of all the land — prime locations for wind and solar farms without great alternative uses. This is also the case in many other countries: governments typically own their countries' deserts and mountains.

An immediate step would be to make it easy for clean-energy developers to lease such land cheaply for 30-50 years if it is for the purpose of building wind and solar farms, with penalties for non-use.

Good News Update in August 2021: More Federal land leasing for clean energy projects has just been made policy in the U.S.!

(11) Kill the Worst Emitters

Among the lowest hanging fruit is shutting down the worst polluters. They are also remarkably easy to identify.

➤ Methane

Natural gas is worse than suggested by its plant emissions. Indeed, it may be no cleaner than coal! This is because too many wells and some pipelines are leaking methane. It is a world-wide problem. Fortunately, the majority of emissions comes from a minority of locations. Even better, satellites make large emitters easy to detect. Governments should immediately send crews to flame off or close the leaks. It can be decided later who has to pay for the cost. If need be, allow private-party lawyers to sue for recovery and retain some of the settlement.

➤ Coal

New coal plants are bad, because they release a lot of CO_2. However, old coal plants are worse. They release not only CO_2 but also many other harmful pollutants. Many of these old coal plants are barely economical to run even without fossil fuel taxes. Thus, governments should push them over the edge and immediately close them. With appropriate one-time subsidies and special waivers for many regulatory delays, cleaner plants could substitute for the lost power relatively quickly in many countries. If the subsidies are based on, say, 2015 emissions, they would also not create perverse incentives to build

more polluting plants. Yes, such programs cost money — but they are worth it even for local citizens (and, of course, for the world at large).

(We wish we had good ideas how to stop the imminent construction of coal plants in China, India, and beyond. We do not. What a missed opportunity for the world.)

(12) Negotiate *Some* International Agreements

Most international treaties are not low-hanging fruit. Negotiating over CO_2 emissions seems largely futile to us.

However, there are situations in which international negotiations could work. Our favorite one is methane emissions control that would make it in the interest of countries to eliminate super-emitters. The cost of plugging or flaming off leaks for the worst emitters is low (relative to the worldwide harm) and their actions can be easily verified by satellites. An international treaty, in which rich countries could share some of the cost, could speed this along.

(13) Adapt?

Adaptation to climate change will greatly reduce its harmful effects. It is why hurricanes (Chapter 3) kill far fewer people today than they did 100 years ago. It is why most earthquakes in California have become nuisances rather than catastrophes. It is why Venice and the Netherlands are still above water. The Global Commission on Adaptation 2019 Report estimates that investing $1.8 trillion globally from 2020 to 2030 could generate $3.5 trillion in total benefits – a hefty return on investment when considered from a social perspective!

Yet our book has barely touched on adaptation. There is a reason to this madness. Most of the time, it is in the interest of the involved parties to adapt. It is (or at least should be[4]) in the interest of people not to build houses on the ocean shore at zero elevation or next to dry forests that will burn sooner or later. It is in the interest of countries to build warning systems, dykes, and fire control systems. Adaptation is not really a global problem plagued by a global externality, like climate change, which is the subject of our book.

[4]Some well-meant government insurance schemes have created a moral hazard that will make the matter worse in the future.

Could adaptation be dangerous by substituting for the necessary global fossil fuel detox? Maybe. But we cannot steer the boat (i.e., Earth) back so quickly that we won't need adaptation. And we wouldn't want people not to protect themselves.

With a nod to the Buddha, as far as global adaptation goes, "it is what it is" (or "it will be what it will be"). And as far as our book goes, it is already too long, so we have to punt on this important subject.

(14) Crises Beyond Climate Change?

Bjorn Lomborg has a whole list of global problems that are worth tackling. For the most part, he concludes that fighting climate change through ordinary means today gives too little bang for the buck. (At least, it used to be too expensive. With improvements in technology, which he also predicted, the tradeoffs are shifting.) Other environmental issues brought about largely but not only by our global population explosion — like eradicating global hunger or malaria — are comparably much cheaper. They could be accomplished for a tiny fraction of the cost of premature decarbonization..

It is difficult to choose among worthy causes for humanity and beyond. habitat destruction, species extinction, and overfishing are examples of impacts that extend beyond the human species. How can we weigh the misery of 3 to 6 million children starving to death or half a million children dying from malaria every year today against the misery of a potentially looming climate catastrophe?

Ideally, "we" would tackle all these problems. As economists, we are schooled in the science of scarcity and tradeoffs. As humans, we find it difficult to judge which miseries are more important than others. These are questions of ethics, and the moral dilemmas posed by these questions weigh heavily on us.

Yet, if our book's main thesis is correct, there really are no tradeoffs between the world spending resources on fighting climate-change vs. fighting, say, extreme poverty. This is because there is no world decision-maker who would trade them off. These very real problems are not going to be solved by a social world planner. They will have to be solved by a collection of about 200 self-interested nation states, thousands of governments, about 1 billion richer people in OECD countries, and about 7 billion poorer people in non-OECD

countries. The only way to change the world is to influence the tradeoffs that these individual parties face.

2 What Can Individuals Do?

We now shift to considering voluntary choices made by individuals — good choices and bad choices; choices that could make a disproportionate difference and choices that will not.

(1) Change Your Behavior?!

There have been many bestsellers that have held forth about how to reduce your carbon footprint. They sell many copies to the faithful, but they are misguided. They would be amusing distractions if only the issues were not so serious, if only the beliefs were not so widely held, and if only the diversions would not delay what really needs to be done.

Why haven't most people voluntarily changed their behavior? Is the problem that they just don't realize how they can reduce their personal carbon footprints or how much it would help the environment?

We would love people to change their ways selflessly, but it's unrealistic. Economics suggests that not enough people will do so if it is not in their self-interest. This implies also that clean energy must not be much more expensive than dirty energy to achieve widespread adoption. It is a fallacy to think that voluntary changes against personal self-interests could transform the world. It won't happen. Don't shoot the messenger. It's not our fault. We did not design the world this way.

Part of our skepticism stems from the fact that behavioral changes significant enough to affect climate would not only have to be widespread but also long-lived. Otherwise, changes have little impact — in fact, almost surely only an immeasurably small impact. Even large changes in response to a crisis lasting only a few years would barely move the needle.

➤ A Historic Carbon Footprint List

Still don't believe us? In his classic and still prescient book Sustainable Energy Without the Hot Air published more than a decade ago and which inspired

us greatly, David MacKay recommended that individuals adopt the following good practices:

- Put on a woolly sweater in winter and turn down your heating's thermostat (to 15°C or 17°C, say). Put individual thermostats on all radiators. Make sure the heating's off when no one's at home. Do the same at work.
- Read all your meters (gas, electricity, water) every week, and identify easy changes to reduce consumption (e.g., switching things off). Compare the results competitively with a friend. Read the meters at your place of work, too, thereby creating a perpetual live-energy audit.
- Stop flying.[5]
- Drive less, drive more slowly, drive more gently, carpool, use an electric car, join a car club, cycle, walk, use trains and buses.
- Keep using old gadgets (e.g., cell phones); don't replace them early.
- Change lights to fluorescent or LED.
- Don't buy clutter. Avoid packaging.
- Eat vegetarian six days out of seven.

None of these recommendations should come as a surprise. They are about as widely known as "eat less sugar and exercise more — it's good for you." The appendix summarizes similar but more lists from the EPA and other climate-conscious websites.

The sad fact is that these suggestions read a lot like New Year's Resolutions or diet plans. They begin with great excitement and commitment but then fade quickly. Unfortunately, evanescence won't work for climate change. The necessary behavioral modification must last multiple lifetimes, because even future generations will have to adopt them; and they must occur not just in the West but all over the world.

Reading through the list today, we note that the only one that has had widespread and lasting impact is switching lights — and it is not due to environmental aspirations. It is due to technological improvements and mass production that have made LEDs both cheaper and better than incandescent

[5] Recall Chapter 1. Flying is probably the fastest way for an individual to rapidly increase her carbon footprint. Cutting airplane travel is more important than everything else on this list — even for environmentalists.

lights. Electric cars are about to become a second example of a technological transition. Of the entire list, only the ones due to technological change will have worked. Even the more modest "sweater" recommendation is a no-go. Comfort and self-interest come first when it comes to large populations.

➤ Setting an Example

What about setting an example? Of course, if you are the Pope, the Archbishop of Canterbury, or the Orthodox Ecumenical Patriarch, your example and joint appeal may matter. However, if you are like the rest of us, don't overestimate your importance. Frankly, the world does not care what your thermometer reads or whether you eat vegetarian or not. Of course, none of MacKay's recommendations are bad — most of them are outright healthy for you, and we encourage you to follow them. (And please exercise more, too.) Just don't think that your actions and those of your friends will make a difference to the CO_2 concentration in the atmosphere. The statement "if everyone did it" is a fallacy. (If everyone does it, it will have nothing to do with you; your eating steak won't change everyone.)

➤ Carbon-Shaming

What about carbon-shaming others? Fat chance. It may make you feel morally superior, but it is more a sign of ignorance about what really matters than it is an effective climate-change strategy. And even if you are the world's greatest carbon-shamer, convincing everyone you will ever meet, *it doesn't matter*. The world only cares what hundreds of millions of people eat, not what you and your friends eat. The world does not care whether you fly across continents, sail across oceans, or stay home altogether. The world only cares if hundreds of millions of people do so. Realistically, you can't shame even a significant fraction of so many people.

(2) So What Can You Do?

We are all little cogs in a big machine of eight-thousand million people. By far, the best contribution you can make is to play a small part in moving the large collective — not playing a large part in moving a small collective.

Thus, you can do more to combat climate change by working on inventing and deploying new, clean technologies than you could ever possibly do by decarbonizing your local neighborhood. Only better technology can move the needle. Your neighborhood deployment cannot.

The best advice we can give to climate activists is to bicycle to work not for the sake of the planet but for the sake of fun and exercise. The best advice for the sake of the planet is to get involved in clean-energy research, development, and implementation.

Business and economics are not the enemy. They are part of the solution. Often the most difficult aspect of new technologies is cost-effective implementation. Elon Musk is not an inventor. He is, however, the greatest technological innovator of our time. His entrepreneurial talents have almost single-handedly pushed the United States back into a leadership position in both cars and rockets. Inventors are a dime-a-dozen. Visit the laboratories of your local university, and you will find hundreds of fascinating inventions. Elon Musk's brilliance has been his ability to jump start the deployment of important large-scale generation-leaping inventions.

There are also other ways to help. Politicians can help convince the public to make better choices and occasionally even sacrifices. Journalists can help capture the attention of readers. Academics and authors can help educate the next generation about what is important. Climate activists and environmentalists can help prick our conscience and help maintain public support. Religious leaders can help foster the common good and appeal to our less-selfish instincts. Philanthropists can help, at least a little, where government has failed — this includes Bill Gates, whose initiatives in the third world and in the energy sector are a blessing for humanity.

In our minds, the best way to help humanity now remains researching, developing, and implementing scalable clean-energy technologies. Getting rich in the process is merely a nice bonus for those who end up making a contribution.

What would we recommend to our own children? What can they do? What can you do?

- Build your career in science and technology related to climate change. One path would be studying climate change directly. Another would be doing research related to green energy provision. Yet another would be research on improving agricultural processes.
- Become an entrepreneur or work in the clean energy space. Elon Musk has moved the needle far more than the entire United Nations — with all its Rio, Kyoto, Copenhagen, Cancun, and Paris conferences. So have Lewis Urry and Sony with their Lithium battery work. So has our colleague, Lesley Marincola, who is trying to bring small-scale solar energy to the poorest of the poor. There is room for thousands of start-up firms exploring new ways to accelerate the transition for millions. Don't feel guilty if you get rich off it, too.
- Lead others. As much as you may dislike politics, government is the only institution capable of significantly accelerating the transition to a clean economy. For those who have the stomach and the talent, government service is a route to consider. If you do so and when you get there, don't fall for futile showy green policies that won't accomplish much in the end. Instead, expand your country's research, development, and initial deployments of green technology.
- Pursue a relevant teaching career. There is so much misinformation out there — some intentional, some ignorant — that helping educate the public about the science and economics behind climate change is an important undertaking. Educate people about what really matters. Inspire them.
- Write a book. Remain honest even when it is uncomfortable. Give the people the red pill. Tell them what the problems are, what can be done about them, and what truly matters. Don't argue for the sake of winning or dogma. The point is not to win an argument. It is to search for better solutions — including solutions that we did not propose.

  That is what we have tried to do here. It is why we wrote this book.

Conclusion

Why did we think the world needed another book about climate change?

First, we thought we could explain the issues better and do so in a way that had no partisan or home agenda. Second, we wanted to contribute to pushing our readers towards more realistic approaches and away from unrealistic ones. Little of what we have written has not already been stated somewhere else. If you already knew it all, we apologize for having wasted your time. If you did not, we hope we helped focus your thinking.

Our book claimed that there is really only one red ace when it comes to reducing CO_2 in the atmosphere: technological advancement. There are two more picture cards: locally justifiable taxes on fossil fuels (for the sake of reducing co-pollution) and tree planting. There are also many non-face cards that can and will help. But nothing else will come close in importance to technology improvements.

Other commonly proposed solutions are too limited, too unrealistic, too expensive, suited only to rich countries, or all of the above. If the 1-2 billion people living in the richer economies cannot find solutions that will induce the poorer 6-8 billion people to leapfrog over fossil fuels, the world's CO_2 emissions will not decrease but increase for decades or centuries.

Humanity has been luckier than it could have hoped. Technology has been improving at a rapid rate despite far less government support than collectively optimal. (Humanity must increase it!) As economists, we believe that real-world governments' best role is to facilitate the transition. They cannot execute it by decree. With intelligent government support, individual self-interest and competition can work wonders. We are optimistic that human creativity can then quickly reduce greenhouse gas emissions. But we must not be complacent. It is in the self-interest of virtually all countries and especially rich countries to work on accelerating progress.

From our small selves to the governments of the world: Please subsidize green research, development, and first deployments far more than you have in the past.

This is the best way to "move the needle now."

Further Reading

Books

- John Doerr, 2021, Speed and Scale, Random House.
- Gates, Bill, 2021, How to Avoid a Climate Disaster, Knopf, New York. A guide to reducing emissions from the leading philanthropist of our times.
- Global Commission on Adaptation, 2019, Adapt Now: A Global Call for Leadership on Climate Resilience. A comprehensive analysis of the costs and benefits of adapting to climate change.
- Lomborg,Bjorn, 2020, False Alarm, Hachette Book Group, New York, 2021. An alternative view of the costs and benefits of climate change choices — well-intended and posing profound dilemmas — but misguided in one sense: there is not a global entity that could make such choices.
- Nordhaus, William 2018, Climate Change: The Ultimate Challenge for Economics, Nobel Prize Lecture.
- Thaler, Richard H. and Cass R. Sunstein, 2021, Nudge: The Final Edition, Penguin Books, New York. Steps that government can take to overcome human inertia.
- We share many views with Ken Caldera, who now works as an advisor to Bill Gates — from geoengineering merely being a mask, to exploring many different technologies, to keeping a skeptical but hopeful perspective on nuclear power.

Reports and Academic Articles

- Aldy, Joseph E. and Richard Zeckhauser, 2020, Three Prongs for Prudent Climate Policy, Resources for the Future Working Paper.
- Borenstein, Severin, 2005, The long-run efficiency of real-time electricity pricing, The Energy Journal.
- Matthews, H. Damon, et al., 2021, An integrated approach to quantifying uncertainties in the remaining carbon budget, Communications Earth & Environment. (About 0.44°C per 1,000 $GtCO_2$.)

Shorter Newspaper, Magazine Articles, and Clippings

- Marshall, Aarian and Matt Simon, Adapting our rich cities21st-century storms are overwhelming 20th-century cities Ars Technica, 2021/09/06.
- Climate Appeal by Medical Journal Editors, September 6, 2021.
- DOE Signs Up 125+ Local Governments to Fast-Track Solar Permits, September 28, 2021.
- Taylor, Adam, et al., Nov 10, 2021, 2C or 1.5C? How global climate targets are set and what they mean, Washington Post.
- Timmer, John, Most of the power sector's emissions come from a small minority of plants. Ars Technica, 2021/08/11.

Websites

- National Academies of Sciences, Engineering, and Medicine, Division on Earth and Life Studies. Has, e.g., suggestions for foundational research for ocean carbon sequestration, fusion, and reflecting sunlight.

App. A Some Exciting Green Tech

We are not engineers, but we want to share our own interest and excitement about some technologies that could potentially change the world.

- Any new technologies that are grid-scale electricity storage related and promising are of great interest to us. Lack of adequate scalable electricity storage is the only remaining hindrance to wind and solar taking over the world.

  For instance, where can exhausted gas wells and other underground caverns serve as compressed-air storage at large scale?

- Safe nuclear fission power plants with minimal waste. Once built, their power could be so cheap that even natural gas would be more expensive. There are no scientific reasons why it should not be possible to design fission reactors that can intrinsically no longer explode and that can reuse their fuel a thousand times more often than they do today. However, for decades, the world has not deployed many new reactors, and nuclear technology learning has crawled along way too slowly.

  Regulation (with good intent but perhaps not good reason) has made any plant changes almost impossible, leading companies to prefer to work with known but ancient, intrinsically dangerous technologies (pressurized water reactors, where cooling failure can lead to meltdowns) rather than with unknown but potentially safer technologies (where cooling is passive and not dependent on a backup power source, so that even if the operators make stupid mistakes, as they did in the Chernobyl disaster, the plant cannot blow up). The goal should be to build a reactor in which even the most malicious black-hat operators and hackers could no longer make the plant release radioactivity.

  Such a reactor should also not produce weapons-grade material, be small in size (to be shipped and assembled on-site), and mass-producible. Pebble bed reactors seem like excellent candidates. Offering leasing / financing to countries that are willing to replace coal plants with these small reactors would further broaden their reach. Finally, there should be a concerted plan to reprocess the fuel in breeder reactors instead of governments guaranteeing non-existent long-term storage of spent high-level waste.

  This is *not* the nuclear industry of today. However, it could become the nuclear industry of tomorrow.

- Nuclear fusion: The National Academies of Sciences' target for a prototype plant should be 2040. There are still many technical challenges to overcome, but fusion promises virtually limitless safe energy without waste products *if* it could be made to work. It may not work, but it's worth a shot.

  Note that from an economic perspective fusion is often misunderstood. Fusion plants will be more akin to super-safe nuclear fission plants with no waste

fuel than something entirely different. Both fission and fusion plants have extremely high fixed costs and negligible fuel costs. The fact that fusion uses a different, inexhaustible fuel is unimportant. There is more than enough dirt-cheap uranium and thorium to run traditional nuclear power plants at almost zero fuel cost for a thousand years.

- Industrial high heat. Could small nuclear reactors be used not only for electricity production but for industrial heat?[6]
- Geothermal power could potentially tap more heat from our planet. All it really requires seems to be a very deep hole (and some water). Could the cost be reduced by an order of magnitude?
- Though we are generally skeptical of carbon sequestration because there are few private incentives here, tree planting and advanced olivine weathering for accelerated carbon removal are potentially cheap and deserve further RDD.
- Solar radiation management (SRM). This could involve injecting reflective sulfur particles into the upper atmosphere to reduce the amount of radiation that is absorbed by the Earth. The cost is remarkably low. Can we try this in very small scale and learn what it does?

[6]Nuclear reactors may not be what you think they are. Even a 14-year-old managed to build a basic reactor by himself.

App. B Recommendations By Others

Many individuals and organizations have offered suggestions (often in list form) for how greenhouse gas emissions could be reduced. This appendix describes some prominent such lists. ***Please*** **bring prominent important lists to our attention. We would be happy to reference more of them.**

Note that we describe the suggestions here even when we do not believe that they will move the needle on climate change. We have no qualms doing so: many of these suggestions are laudable, wholesome, and commendable — as is exercising more. We would love populations all over the world to follow them, but we suspect that their uptake will be limited. However, some of these recommendations are also cost-efficient even for the parties involved, and nudges could further improve their uptakes. Without further ado, here they are.

(1) Environmental Protection Agency

The Environmental Protection Agency (EPA), founded in 1970 by a Republican president, is the most prominent and powerful environmental agency in the world.

The EPA is pursuing a number of initiatives intended to reduce GHG emissions:

- Measuring and reporting GHG emissions and sinks.
- Works with industry to reduce emissions.
- Cost-benefit analysis for policy.
- Science support (incl. wildfire research).
- International partnerships.
- Community aid.
- Information and education.

The EPA also posts recommendations for individuals and businesses. Following the EPA's own order, they are:

Energy:
- Look for Energy Star certified energy-efficient products.
- Live in an Energy Star certified dwelling.
- Heat and cool more efficiently (insulation, etc.).
- Adjust thermostats.
- Switch to green power (e.g., rooftop solar, rooftop garden); buy green power.

Waste:
- Buy less new stuff, if so with more durable, sustainable, and recyclable components.
- Reduce food waste, compost.
- Reuse old clothing, bags, etc.
- Buy used.

- Recycle.

Transport:
- Bike, walk, carpool, public transport.
- Drive less aggressively.
- Switch to energy-efficient and/or electric vehicle.
- Make fewer trips.

Water:
- Turn off running faucets, run clothes washer with full loads and cold water.
- Use energy-star water-sense certified dishwasher — better than by hand.
- Plant water-smart landscape.
- Low-flow showerheads, shorter showers.

Environmental Justice:
- Get to know your community and neighborhoods.
- Plant trees, especially in urban environments.
- Learn where large industrial GHG facilities are.
- Learn about local powerplants.
- Communities can find lowest-price energy-star certified products.
- Learn about and empower near-port communities.
- Work with neighbors and community to integrate smart growth and environmental justice.
- Join local advisory boards.

More:
- Educate children and young adults.
- Environmental stewardship to reduce GHG emissions.
- Estimate annual GHG emissions.
- Participate in citizen science by sharing data.
- Tell others.

(2) Project Drawdown

Project Drawdown is a prominent nonprofit organization that collects and disseminates suggestions for how to reduce global warming. Following their recommendations in order:

Electricity:
- Enhance efficiency to reduce demand.
- Shift production to avoid fossil-fuel use.
- Improve transmission grid and energy storage.

Food, Agriculture, Land use:
- Shift diets lower on the food chain and address food waste.
- Protect land and ecosystems. Improve farming productivity.
- Change farming practices (e.g., rice and cows).

Industry:
- Improve materials, esp. plastic, metals, and cement.
- Reuse waste.
- Improve refrigerants (CFCs).

- Enhance process efficiency.

Transportation:
- Public transport and ride-sharing.
- Improve fuel efficiency in combustion engines.
- Electrify vehicles.

Buildings:
- Enhance efficiency (insulation).
- Use alternatives for heating.
- Improve refrigerants (CFCs).

Land Sinks:
- Reduce food waste, eat vegetarian. Reduces deforestation.
- Protect and restore ecosystems.
- Change agricultural practices.
- Improve degraded land.

Coastal Sinks:
- Protect and restore ecosystems, esp. mangroves, salt marshes, seagrass meadows.
- Investigate seeweed and kelp farming.

Other: Project Drawdown also suggests investigating engineering sinks and improving health and education.

(3) Clean Technica

Clean Technica is an prominent environmentally focused website. It's list is somewhat unusual, in that it starts not with what we should be doing, but what we should *stop* doing that is outright stupid. It is hard to argue with Clean Technica's analysis.

- Stop ethanol subsidies.
- Stop fuel cells for light vehicles (cars and trucks), rather than batteries.
- Stop carbon capture and sequestration. Don't use fossil fuels.
- Continue existing nuclear reactors, but don't build new ones.
- Stop fossil fuel subsidies.
- Stop blue hydrogen (requires carbon-capture and sequestration).
- Stop biofuels. Wind, water, solar is much more efficient.
- Stop using natural gas (methane).

Reading the above suggestions is depressing in that we also wish they were addressed sooner rather than later. Clean Technica also does offer "smart" positive suggestions, though:

- Wind, water, solar.
- More wind, water, solar — overbuild.
- R&D, especially grid-based storage technologies.
- R&D for long-distance high-voltage DC transmission lines.
- Move to battery-electric vehicles.

- R&D for electric ocean propulsion, long-distance trucking, short-haul aircraft.
- R&D for hydrogen propulsion for long-distance aircraft.
- R&D on industrial heat-related processes.
- Follow Marc Jacobson's suggestions. Note: there is controversy among scientists whether his ideas are enough to decarbonize the US. However, there is little controversy that many of his suggestions would make for good policy.

For personal use, Clean Technica recommends

- House solar panels.
- Don't buy another gas car.
- Don't eat meat.
- Use only LED lighting.
- Use heat-pump based heaters.
- Check insulation.
- Buy energy-star rated appliances.
- Set thermostat appropriately.
- Turn off devices when not in use.
- Avoid refrigerators and freezers, unless absolutely necessary.

(4) Global Methane Initiative (GMI)

The Global Methane Emissions and Mitigation Opportunities Factsheet describes not only sources of methane emissions, but also opportunities to reduce them. Because Methane is such a powerful GHG with shorter-term effects than CO_2, mitigation can work more quickly and efficiently than CO_2 mitigation.

The recommendations are always to capture and channel methane gas instead of venting it. At the end, the methane can be used to power devices (such as engines) or if this is not possible, flared off. This can be done in

- Agriculture, mostly manure-management.
- Mining, active or abandoned mines.
- Municipal landfills.
- Oil & gas systems.
- Wastewater and sewage.

In addition, the GMI recommends measurement and detection. (Methane leakage shows nicely on infrared cameras.)

(5) A Few More Suggestions For a List

We want to emphasize a number of further "listable" suggestions:

- Establish strong penalties for methane leaks that are not immediately fixed. Allow government to intervene and later charge for fixing leaks that are not immediately fixed.
- Offer financing to poorer people (and countries) for the higher upfront cost of clean energy.
- Buy out and close the worst coal plants, not just domestically but internationally, *and* help retrain their workers, possibly in clean-energy installation jobs — a position now endorsed even by the Coal Miners' Unions). Have the OECD subsidize some of the cost in third-world countries, especially if these countries agree not to build more coal plants.
- Investigate seasonal roof color choices to capture solar heat in winter and reject it in summer.
- Improve awareness of heat pumps and heat storage. Heat pumps are almost magical devices. They produce heat at far lower cost than all other alternatives.
- Stop installing natural gas lines into new buildings (as in California).

And, of course: clean R&D, more R&D, and more R&D.

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