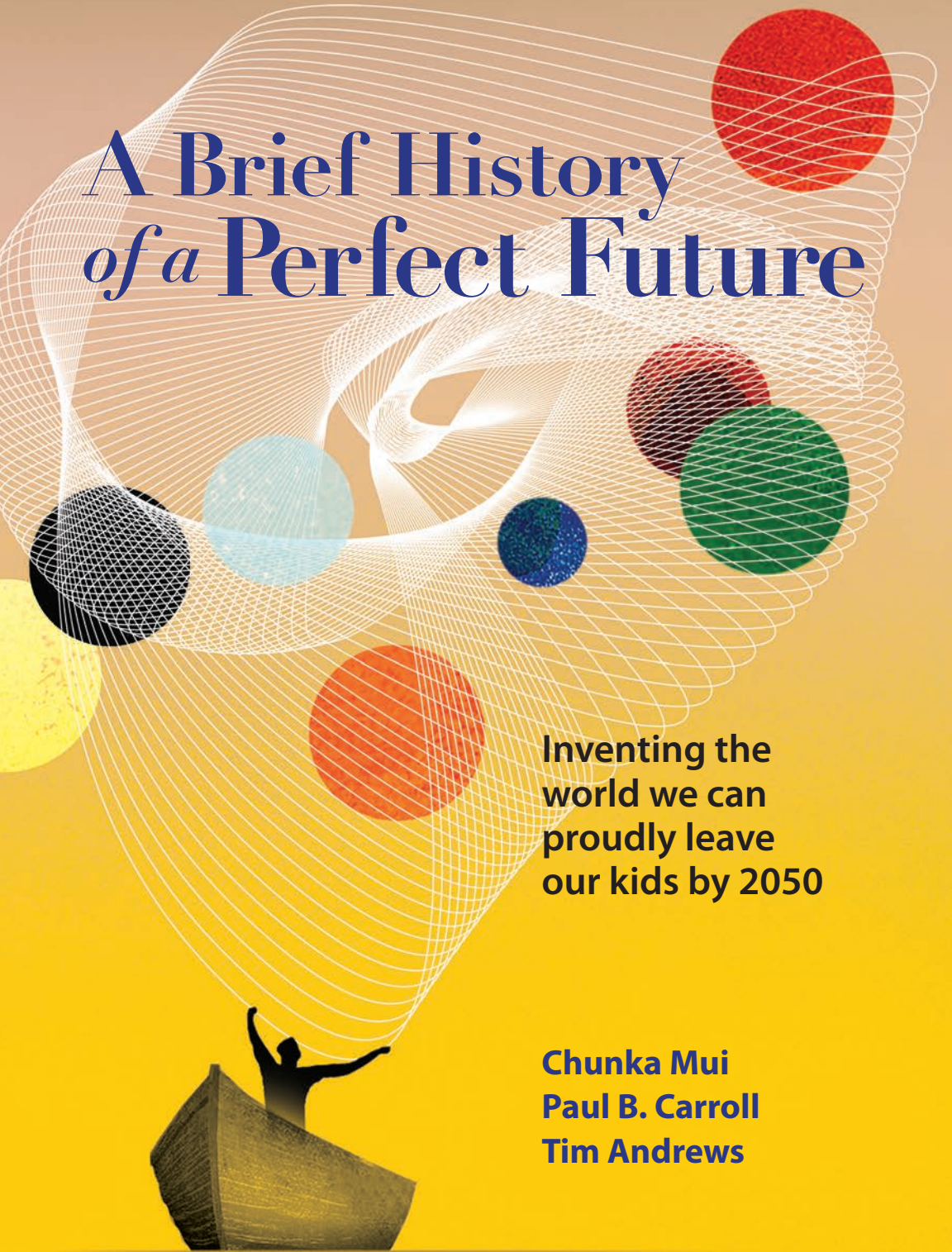
A Brief History *of a* Perfect Future



Inventing the world we can proudly leave our kids by 2050

Chunka Mui
Paul B. Carroll
Tim Andrews

A Brief History *of a* Perfect Future

Inventing the world we can proudly leave our kids by 2050

Chunka Mui
Paul B. Carroll
Tim Andrews

FUTURE
HISTORIES
PRESS

Copyright © 2021 by Paul B. Carroll and Chunka Mui

All rights reserved. No part of this book may be reproduced or used in any manner without written permission of the copyright owners except for the use of quotations in a book review.
For more information, address: chunka.mui@gmail.com

This work contains elements of creative nonfiction. Names, characters, places, and incidents in the book's "future histories" either are the product of the authors' imaginations or are used fictitiously in varying degrees, for various purposes.

Cover and interior design by Alan Barnett
Cover design guidance from Mark Maltais
Cover illustration by Brian Stauffer

Published by Future Histories Press
www.perfectfuturebook.com

From Chunka, Paul, and Tim

To our kids, Zoe, Kai, Clare, Shannon, Tyler, and Brett
(and, of course, to their moms, Beth, Kim, and Valerie).

To our kids' kids—and to theirs, on down the line.

To your kids.

CONTENTS

Introduction: Inventing the Future 1

PART ONE: THE LAWS OF ZERO 13

Chapter 1 The First Law of Zero: Computing 19

Chapter 2 The Second Law of Zero: Communication 25

Chapter 3 The Third Law of Zero: Information 29

Chapter 4 The Fourth Law of Zero: Genomics 35

Chapter 5 The Fifth Law of Zero: Energy 45

Chapter 6 The Sixth Law of Zero: Water 55

Chapter 7 The Seventh Law of Zero: Transportation 59

PART TWO: THE FUTURE HISTORIES 65

Chapter 8 Electricity 73

Chapter 9 Transportation 87

Chapter 10 Health Care 101

Chapter 11 Climate 123

Chapter 12 Trust 147

Chapter 13 Government Services 161

Coda What if the Future Isn't Perfect? 177

PART 3: JUMPSTARTING THE FUTURE 183

Chapter 14 What Individuals Can Do (Starting Now) 187

Chapter 15 What Companies Can Do (Starting Now) 197

Chapter 16 What Government Can Do (Starting Now) 207

Prologue: Over to You 223

Acknowledgments 227

Endnotes 231

Index 243

INTRODUCTION

Inventing the Future

When Xerox CEO C. Peter McColough established the Palo Alto Research Center (PARC) in 1970, Xerox executives were, naturally, curious to know what their corporate crystal ball would tell them about the future of computing. When Alan Kay, a team leader at PARC, was asked for the umpteenth time to say what the future would hold, he snapped there was no easy way to know. "The best way to predict the future is to invent it," he said.*

That line became a mantra for Alan and for PARC, which did unbelievable amounts to invent the future by laying the foundation of today's computing experience. It also became a mantra for the three of us, as we worked with Alan for decades, and it drives the narrative of this book. In the following pages, we'll lay out ways that we, as a society, can harness the technological marvels at our disposal and invent a sparkling future.

At PARC, starting in 1971, the mantra played out over five glorious years as researchers invented many of the core elements of information technology. Alan's team contributed to the development of the first personal computer and gave it the overlapping windows and graphical user interface that Steve Jobs copied for the first Apple Macintosh. Alan invented (with Dan Ingalls) what today would be called dynamic

* Alan tells us that while his well-known line was a spontaneous utterance in 1971, "the idea is a simple one, sure to be invented many times." Alan nods to many who came up with variations of it previously, including Abraham Lincoln, Peter Drucker, and Dennis Gabor.

object-oriented programming (which is a big reason you have so many apps on your smartphone; developers can easily incorporate software "objects" others have already written, rather than having to write all the code from scratch). Other teams at PARC developed desktop publishing, the laser printer, peer-to-peer and client-server computing, and Ethernet, which enabled corporate networks of personal computers.* And, while PARC didn't invent the internet, its researchers made such significant advancements that PARC deserves considerable credit for it.

A half-century later, most of the information-technology industry and much of global culture and commerce still depends on PARC's inventions. Technology companies and many others in downstream industries have collectively realized trillions of dollars in revenue and tens of trillions in market value because of PARC's work.

When PARC began its work in 1971, what most people thought of as a computer weighed more than a ton, needed to be cooled with water in a heavily air-conditioned room, took about 15 minutes to boot up, and was surrounded by a sort of priesthood of lab technicians in long, white coats to cater to the needs of the machine. Data was entered with punch cards, and results were produced on clackety printers as words and numbers—there was maybe the occasional graph, but certainly no images, and the idea of video on a computer was positively silly. The internet existed, but barely—while tens of billions of devices are connected these days, only four computers were tied together in the early days. Not four billion. Not four million. Not four thousand or even four hundred. Four.

Computers in 1970, with far less power than today's phones, looked like the ones shown in Figure 1.

But Alan had developed a series of very different ideas as a graduate student in the 1960s, and they would lead to what he eventually called Dynabook—a battery-powered laptop with wireless access to a network

---

* While Xerox is often derided for not capturing anything close to the full value of PARC's inventions, we think McColough is one of the unsung heroes of innovation. He invested in PARC for years, taking money out of the bonus pool for himself and other executives, even though Xerox didn't see the big payoff until after he retired in 1982. That payoff was enormous: more than $100 billion in sales of laser printers. For what it's worth, McColough also established one of the first affirmative action programs at a major corporation.

FIGURE 1. A typical data center circa 1970

that let you communicate with anyone and have access to all the world's information.

In a world full of mainframes, Alan imagined computers more like the ones pictured in Figures 2 and 3.

Then he and the team at Xerox PARC invented that future.

Alan didn't wait 30 years to say, "Wow, I sure have access to a lot of computing power now; what should I do with it?" He and his colleagues at PARC envisioned a radically different educational tool that they could build around that power and use to provide a new kind of literacy and new meanings for "reading" and "writing" so children could discuss, play with, and learn powerful ideas. Then Alan and PARC imagined all the pieces that would be needed. Some related to the computer itself—the kind of operating system that would tap into the new power, the windows that would let users flip easily between tasks, etc. Some related to supporting devices, in particular to capabilities for networking

FIGURE 2. The Flex Machine, drawing by Alan Kay, 1968

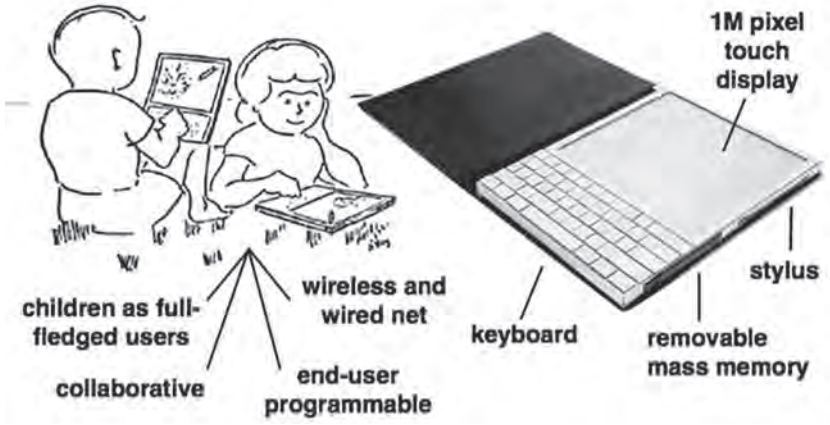


FIGURE 3. The Dynabook, drawing by Alan Kay, 1972

computers and for printing. PARC then moved in a host of directions at once. The whole computing environment, not just the processor, gained momentum quickly. We're all better off as a result.

Alan invented a future a second time, too.

As an Apple fellow, he helped pull together a vision for a so-called Knowledge Navigator, unveiled in a video in 1987. The device bears an eerie resemblance to the iPad, introduced 23 years later. While Steve Jobs obviously shaped the iPad in his own brilliant way, the vision in the Knowledge Navigator videos clearly guided research in Apple's labs for years before Jobs got involved.

For good measure, Apple's work on the iPad gave the company the biggest gift in the history of business: the iPhone. According to Jobs, when he decided the iPad wasn't ready for production, he realized the technology could be packaged into something much smaller—a revolutionary phone.[1*] *Et voilà!* Neither Apple nor the world has yet recovered.[2] (In the pre-iPhone world, in 1996, Apple almost sold itself to Sun Microsystems for about $4 billion; as of this writing, Apple's market value is $2.34 trillion.)

The idea of inventing the future surfaced anew for the three of us as we tried to make sense of the dysfunction in the U.S. in recent years—on politics, race, the pandemic and other public health issues, social media and disinformation. As we write this in the summer of 2021, the Gulf of Mexico is on fire, a condo building just collapsed in south Florida and killed scores of people, and a town in Canada burst into flames and burned down as a "heat dome" repeatedly settled over much of North America. One of Paul's daughters sent him a panicked text: "There is no Planet B!" One of Tim's sons told him, "You're worried about whether your Social Security benefits are going to be cut; we're worried about whether there's going to be a planet left by the time that's an issue for us!" Chunka's daughter noted that he's often described as a futurist and once quipped to him, "Well, then you'd better not mess mine up."

Can we reassure our kids, honestly, or are we doomed to a dystopian future? There sure is a lot going wrong.

---

* When Jobs introduced the iPhone in 2007, he explained Apple's decision to build its own phone by quoting Alan as saying: "People who are really serious about software should make their own hardware."

As is our nature, we've settled on hope. We think we can envision a grand future, putting a stake in the ground for our kids and their kids, then draw on our decades of experience evaluating technology trends to start inventing what we're calling a Future Perfect.

We're not saying we can predict the future. We very much abide by the oft-used line that "it is difficult to make predictions, especially about the future." Besides, at their best, predictions represent the most likely outcome, and in pivotal times like today's, the most likely scenarios might well be ones that we want to avoid. No, rather than predict the future, we want to draw on what we've learned from Alan Kay. We want to invent it. More precisely, we want to help you invent it.

Following the pattern Alan has laid out for us, we'll use this book to take you 30 years into the future and describe technological marvels that will be available to us all. These marvels are hard to envision today. While we can all get our heads around a two-fold improvement in something, it's extraordinarily hard to imagine three decades of the sorts of two-fold improvements in computing power *every 18 months* that Moore's law was providing to Alan and his colleagues at Xerox PARC. How do you even process the idea of the MILLION-fold increase in computing power over 30 years that they were designing into their work? So, we're going to try to do that imagining work for you and describe seven so-important-as-to-be-almost-magical technological building blocks that will be available to all of us in 2050.

We'll then paint some pictures of how those building blocks could be supplemented by other technological improvements and novel ideas that, together, will let us construct that Future Perfect. As amazing as these technological marvels will be, the building blocks are not the building. In fact, they could lead to an infinite number of buildings. So, we'll apply "systems thinking" as much as possible to consider how all factors interact and to point us toward a future that is optimized as broadly as possible, not optimized for each of its parts. As we'll explain more in the introduction to Part Two, too much planning has historically been done in silos—so we wind up with city streets optimized for traffic, for instance, but not for people (and we care much more about people than we do about cars). We all need to make this difficult mental effort (ecosystems are really complex), or we may waste the fabulous power these building blocks will provide us. We want you to get

excited about the possibilities of these technological marvels while also seeing the sort of work we all should be doing now to prepare for their possibilities.

Technology will give us great gifts by 2050 no matter what we do, so we could let development happen on its own and then figure out how to react. But we think it would be much better to start planning for the implications—like experimenting now with how cities could be rethought based on driverless cars and some other technological wonders. Why wait 30 years to start learning when we can already see at least the outline of what's coming?

To provide the groundwork for that planning, we'll not only describe the technological marvels but will paint visions of 2050 based on what we call "future histories"—short, provocative "news" articles set in 2050 that describe how key aspects of the world might look in areas such as transportation, health care, and the electric grid. We'll then provide you with tools you can use to envision and write your own future history, for whatever part of the world you think is especially important and that you could help invent by 2050.

Then we'll hand the keys over to you, encourage you to start right away on inventing your piece of the future, and wish you luck. So, yes, we're leaving the hard part to you.

But we hope that, along the way, we'll have stretched your thinking a bunch and given you a powerful way to get started. If we all do our part, we can at least get close to that Future Perfect. If not, we may stumble our way into what we call the Future Pathetic—think *Brave New World* or *1984*. As we all see from what's happening around us today, technology can cut both ways. It can produce great gains—but dystopia is out there, too.

Let's harness the future, rather than just taking our chances.

• • •

We've done this sort of Future Perfect planning for major corporations for years, both separately and together, since the three of us were partners at Diamond Management & Technology Consultants, which pioneered the idea of "digital strategy" in the mid-1990s. After we all left the firm, Paul and Chunka collaborated on a massive research project that led to their 2008 book, *Billion Dollar Lessons: What You Can Learn From the Most Inexcusable Business Failures of the Last 25 Years*. They

then founded a boutique consulting firm, the Future Histories Group, where they help companies spot potential pitfalls, then project out several years to envision an idealized, but plausible, world. Tim went the big-firm route, taking on senior technology roles that led him to his current position at Booz Allen. When the three of us began working together on a project in 2019, and Booz Allen agreed to collaborate on a book related to it, we decided to write a future history for those who really matter: our children and theirs.

Booz Allen became the final piece of the puzzle. The firm provided access to a broad array of experts who sharpened our thinking in numerous ways and encouraged us to expand our scope to include the future of trust, security, privacy, and government services. Given the firm's long history of consulting with government on major projects, Booz Allen also enriched our understanding of how government entities can play the key role that we need them to play to get to our Future Perfect. (Although we won't call out each one, Booz Allen is involved in most of the government examples we cite in the book.)

When writing this book, we took some encouragement from what some are calling "the optimism beat"—a growing body of literature that shows that, despite the pessimism created by the drumbeat of negative news, the world is becoming a much better place. Poverty is way down. Life expectancy has fully doubled globally in the past 100 years. Educational levels are way up, even in developing countries. Crime is down. So are deaths from wars—from terrorism, too, even though it worries so many of us.* Now, the gains from all this good news are spread far too inequitably. For instance, while infant mortality is down in the U.S., the improvement is much greater for whites than for Blacks and other minorities. While incomes are rising, the disparity between Blacks and whites has not narrowed since the 1960s. Gender disparities in wealth and income also stubbornly persist. But there are still broad gains around the world, and they justify optimism.

---

* A plethora of books provides stats and analysis both for the trends and for why they're occurring. Among our favorites are: *The Better Angels of Our Nature: Why Violence Has Declined*, by Steven Pinker; *Abundance: The Future Is Better Than You Think*, by Peter H. Diamandis and Steven Kotler; and *Factfulness: Ten Reasons We're Wrong About the World—and Why Things Are Better Than You Think*, by Hans Rosling, with Ola Rosling and Anna Rosling Rönnlund.

Our tracking of technology trends underscores the cause for hope. The trends are creating so many, many, many more resources for the world to use to tackle its problems. We've been around long enough that we aren't Panglossian about technology—watching something like virtual reality come and go and then come and go again as an all-purpose solution over the past 30 years provides cause for being careful. But we can still look at the future and say, based on the technological marvels we expect to see: "Okay, 30 years from now, what would it be crazy for society not to have?"

We've created what we call the Laws of Zero to summarize the seven main building blocks that we've promised you and that can be used to invent the future—costs are dropping so fast in these seven areas that you can think of them as heading toward zero(ish), meaning that an infinite(ish) amount of that resource will be available. These areas are: computing, communication, information, genomics, energy, water, and transportation.

The easiest Law of Zero to grasp concerns the cost of computing, because we've all seen the stunning and unrelenting improvements in cost/performance for decades now. The cost of a gigabyte of memory, for instance, fell from $500,000 to just two cents over 30 years. We use so much memory these days that no one would say it's free, but if you're thinking about something costing you $500,000 per unit today and can imagine a price of two cents, well, that feels pretty close to free, right? You'd certainly be inclined to use a lot more of that resource to address a problem or opportunity. The cost of phones and bandwidth follows the same sort of plunging curve as computers, giving us our second Law of Zero. Because of the plummeting costs of computers and phones in all their forms—including satellites and tiny sensors—the world will be so wired that the cost of information will also head toward zero cost, and any information you want will be available.* The rapid reductions in the

* Yes, we're waving our hands over some real economic issues here. In some cases, we're talking about zero total cost. In more cases, we're talking about zero marginal cost—or a combination, such as when someone primarily buys a smartphone to use an app like TikTok or Google Maps and basically gets the ability to make phone calls thrown in for free. For now, it's enough just to note the trend toward zero. We'll be more precise as we get into the specifics of the Laws of Zero and the chapters on their implications in key areas of life and business.

cost of genomic sequencing (which have fallen even faster than that of computing) give us our fourth law and provide enormous reason for optimism about our health. There's even reason to project that energy costs are headed toward zero (with some significant caveats). If energy costs plunge, then so does the cost of providing water—which becomes ubiquitous even in many areas that are currently arid. And autonomous vehicles will erase so many considerations of time and distance that the costs of transportation will plunge, meaning it can be envisioned as a nearly unlimited resource. The idea of zero cost may be discomfiting, especially for energy, water, and transportation. We explain our thinking at length in the next section.

Here's another way to think about why we should come to grips with the Laws of Zero and start planning now for 2050: Do we want to be like Norway or like Venezuela?

Both had windfalls from the discovery of enormous oilfields, but Norway used its strategically, while Venezuela used its tactically and meandered into a disastrous future.[3] When Venezuela began discovering massive oilfields during World War I, they led to an economic boom that gave Venezuela the highest GDP per capita in Latin America by 1935, and that boom lasted into the 1980s. But there was no planning for the long term, just reactions to what was happening in the present—and then oil prices crashed in the 1980s. With nothing beyond oil production to rely on, Venezuela descended into social, economic, and political chaos that led to the authoritarian Hugo Chavez and now Nicolas Maduro. Even though Venezuela has the greatest oil reserves in the world, it had a GDP per capita of just $1,700 in 2020. The country ranks 92nd in the world in life expectancy and last in the Americas, at 72 years. By contrast, when Norway discovered rich oilfields in the North Sea in the late 1960s, it strategically invested in ways designed to increase social benefits, including one of the best education systems in the world and a health system so good that life expectancy is nearly 82 years. Norway even poured money into experimenting its way toward a model prison system. It spends roughly three times as much per prisoner as the U.S. does, largely to focus on preparing prisoners to live a crime-free life once they are released—as a result, Norway has one-tenth as many prisoners per capita as the U.S. does.[4] The Social Progress Index ranks Norway as No. 1 in the world, while Venezuela ranked No. 81 out

of the 168 countries in 2016 and wasn't ranked in 2018 because its situation was deteriorating so rapidly that a ranking couldn't be assigned. (The U.S. ranks 28th.)[5]

We'd rather plan like Norway, and we can.

We realize we seem to be swimming against the political tides at the moment. Political factions can barely agree on what day of the week it is, and the 2020 elections have left us with a polarized government (often, a really, really polarized government) at every level. So, this may seem like an inauspicious time to try to rally people around big ideas that will shape our future. But we take encouragement from history. In 1961, when President Kennedy first told Congress of his audacious plan to land a man on the moon by the end of the 1960s, the response was tepid, and 58 percent of Americans opposed the plan.[6] Yet Kennedy managed to pull support together, and the 1969 moon landing is remembered as one of his and the country's great achievements. Even though the political climate in the 1960s was at least as fractious as today's, Congress managed to pass landmark civil rights legislation. And it doesn't matter in the long run whether margins of victory in Congress were small, as with civil rights, or huge, as with the Interstate Highway Act passed under President Eisenhower in 1956.

In fact, we think that right now is a perfect time for discussions on a vision like the Future Perfect. Sure, our political divisions can make it hard to sort through all the near-term issues on, say, health care—"pre-existing conditions," "Medicare-for-all," "the public option" … the list of terms, alone, is onerous. But it's pretty easy for everyone to agree that, in 2050, it'd be crazy for us as a society to not have affordable care available to everyone that keeps them healthier and lets them live longer. If, for the moment, we set aside the question of who should pay—the big issue that divides us—it's straightforward enough to see how the Laws of Zero and breakthroughs in medical technology can get us to both far better care and much lower costs. Long-term discussions simply aren't freighted the way the short-term fights are, and thinking more about the future can actually get people nodding their heads in ways that build rapport. The resulting discussions can then provide context for the actions that need to be taken and for the milestones that need to be reached in the next 10 or 15 years, which can then be turned into factors that need to be considered in our current planning.

The federal government will obviously play a fundamental role by establishing the rules of engagement, conducting basic research, and sparking markets. In recent decades, federal research has given us the internet, the Global Positioning System (GPS), and the core of what's now Google Maps, and it will give us much more by 2050. President Biden believes so much in basic science that he elevated his science adviser to a cabinet-level position for the first time in the nation's history. That new national science adviser, geneticist Dr. Eric Lander, said, "Our country stands at the most consequential moment for science and technology since World War II. How we respond will shape our future for the rest of this century." State and local governments will have a big role to play, too, and they're huge drivers of both the supply and demand for technology through their policy, regulatory, and procurement choices. Business will play its crucial role bringing innovations to market, as companies chase those tens of trillions of dollars of market valuation that exist out there. We individuals will have to do our part, too, as citizens, consumers, employers, employees, and so on.

So, let's set aside the short-term differences for the next 200-plus pages and find a vision that we can all agree on. And let's get excited. The future can be a great place.

On to a Future Perfect!

PART ONE

THE LAWS OF ZERO

CHAPTER 4

The Fourth Law of Zero: Genomics

Our ability to understand and map genetic structures traces back to the garden of an abbey in Moravia in 1856, where an Augustinian monk raised peas. That monk, Gregor Mendel, spent seven years purifying his strains of peas based on seven characteristics, then cross-pollinating the peas to slowly deduce the properties of inheritance. He published a paper in 1865 on a novel theory of what he called dominant and recessive genes—and that was pretty much the end of it. Mendel soon became the head of the abbey, in what is now the eastern part of the Czech Republic, and set aside his scientific work. The paper was promptly forgotten: It was cited all of three times in the next 35 years.[34]

It's fair to say genomics—the branch of molecular biology concerned with the structure, function, evolution, and mapping of genomes—got off to a slow start. But, remember, that's how exponentials work: slow start, overwhelming finish.

Mendel's paper was rediscovered in 1900 and led to a series of discoveries that built on each other and ignited the interdisciplinary branch of science that we now call genomics.* If DNA is "the language in which

* The science of genomics also stands on the shoulders of many other genius researchers, many of whom became well-known but some others who deserve much more recognition beyond scientific circles. Albrecht Kossel discovered the nucleic acids that are the chemical building blocks (called "bases") of DNA and RNA. James Watson and Francis Crick, building on the work of Rosalind Franklin, deciphered the double helix

God created life," as President Clinton once put it, then genomics' acceleration has brought us to the point that we can read and write in the language of life. And in recent decades, the progression, moving even faster than Moore's law, suggests we're very much looking at a Law of Zero: The benefits will keep expanding so fast that we're barely able to discern their outline at this point.

Let's resume the story in 1975, when Frederick Sanger and Walter Gilbert separately unveiled techniques for decoding genes by directly determining the sequence of the bases that make up DNA.[35] The sequencing processes, while miraculous, were arduous. Sequencing required expert laboratory skills and the precise use of dangerous chemicals, including acrylamide (a neurotoxin), chloroform (a carcinogen), and hydrazine (a rocket fuel). Initially, there were no computer programs to analyze the results; researchers had to interpret the results by eye. The entire process of preparing, sequencing, and analyzing even small fragments of the genome was novel and complex enough to earn one a Ph.D.

Tom Maniatis, the head of the New York Genome Center, observed that, when he was a postdoctoral fellow in Sanger's lab, it took him a year to sequence a piece of DNA that was about 35 base pairs. At that rate, it would've taken him 86 million years to sequence the full human genome. Sequencing the COVID-19 virus would have required about 860 years.

But the Laws of Zero feed off each other. And advances in computing, in particular, kept speeding up sequencing. In 1990, the U.S. led the formation of an international cooperative, the Human Genome Project, to sequence the entire genome. Francis Collins was put in charge, and the venture was funded with $3 billion through the Department of Energy and the National Institutes of Health. In 1998, Craig Venter decided that the government effort wasn't moving fast enough and announced a rival, privately funded attempt. A race ensued, and both groups declared success in June 2000, five years ahead of the original timeline for the Human Genome Project.

What had once been a messy problem for scientists handling test tubes and making slides in the lab soon enough became a problem for

---

structure of DNA. Marshall W. Nirenberg and Har Gobind Khorana cracked the code on DNA by showing how the bases determine protein synthesis. And many more.

computers, not just lab technicians—and, as we've seen, computers have become unbelievably fast. Thirty years after Maniatis was a post-doc, the Illumina NovaSeq 6000 machines in Maniatis' center can sequence an entire human genome overnight.

From 86 million years to overnight. Yeah, that works.

Cost comparisons are similar. It cost billions of research dollars to sequence the first human genome in 2003. Today, sequencing a genome costs roughly $600. You can see the plunge in Figure 4. Note that it's logarithmic. The line based on Moore's law doesn't show a steady decline of maybe 50 percent in the cost of computing over the past two decades, as the line would if the chart were using normal, Cartesian coordinates. Each of the horizontal markings represents an order of magnitude, so the chart shows that Moore's law has brought a decline of roughly a factor of 1,000 since 2000—and the cost per human genome has declined far, far faster.

We're not even close to done, either. Multiple makers of sequencing machines predict the path to a $100 genome test doesn't even require further breakthroughs, just incremental technical improvements.

In mid-2021, as we write this, the high-end NovaSeq 6000 in Maniatis' lab costs roughly $1 million, and there are only about 1,000 of them in the world. They're the sequencing supercomputers of the moment. But those prices will come down, and there's no reason sequencers need to stay in labs—think of all the mainframes in computer labs in the 1970s

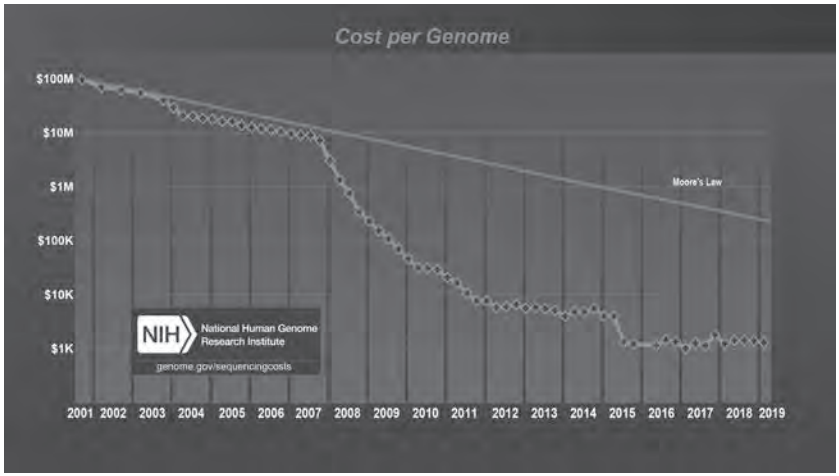


FIGURE 4. Sequencing Cost Per Human Genome 2001–2020

and 1980s, then look at the (more powerful) smartphone in your hand. Even now, lower-power desktop sequencers cost only around $10,000, and there are early versions the size of smartphones, which cost about $1,000. Oh, and there are already attachments that let you sequence a genome from an app on your smartphone.

When will some version of genomic sequencing be embedded in every smartphone (or whatever device the smartphone morphs into)? We don't know exactly, but we're pretty sure that some version of Dr. Bones McCoy's *Star Trek* tricorder is in our future.

In the Future Perfect, you can safely bet the cost of testing will drop so low that you can imagine throwing as much genomic sequencing at a problem as you'd like.* Gordon Sanghera, CEO of Oxford Nanopore Technologies, the company that makes the $1,000, phone-sized sequencing device, describes his company's ethos as "the analysis of anything, by anyone, anywhere."

For a dramatic illustration of the real-world benefits of genomic sequencing today, consider our experience with COVID-19. The genome of the offending SARS-CoV-2 virus was isolated, sequenced, and shared with researchers across the globe within days of when a patient was admitted to the Central Hospital in Wuhan, China, with symptoms of the yet-to-be identified disease. Then, days—we repeat, days—after the sequence was shared, the genetic code of the virus was being used to design the first vaccines, formulate treatments, create testing kits, and monitor for mutations of the virus.

Less than a year later, emergency-use authorizations were approved for multiple vaccines that showed more than 90 percent effectiveness. Soon, millions of shots of those vaccines were being poked into arms to protect those at a high risk from COVID-19, and billions of shots have since followed. Before genomic sequencing, developing and distributing a vaccine could have taken more than a decade—if one ever succeeded.

---

* We'll still have to face the fact that more and better testing isn't always a good thing. Mammograms keep improving, but breast cancer mortality hasn't declined. More and more cases of thyroid cancer are being diagnosed, and more surgeries are being done, but the fatality rate here also isn't decreasing. MRIs to diagnose back pain have made it easier to spot spinal deformities and justify surgeries—that all too often do nothing to alleviate the pain. We'll still have to correlate and make sure that fixing the issues surfaced by genomic testing lead to real benefits and that those benefits outweigh risks and other costs.

The fact that one succeeded, and so quickly, saved hundreds of thousands or even millions of lives worldwide.

And turning back viruses is absolutely just the beginning of what's possible—the very beginning. Even more powerful is the potential ability to write in (or at least edit) the language of life. And we're starting to take baby steps at doing so. Those baby steps are being enabled by a tool named CRISPR/Cas9, called CRISPR, for short.*

CRISPR was invented by Emmanuelle Charpentier and Jennifer Doudna in 2012. The duo and their teams developed it by deciphering and adapting a technique bacteria use to fight viruses. Viruses reproduce by injecting themselves into host cells and taking over the cells' metabolism to reproduce. The host can then fight back by snipping the infecting virus' DNA out of the host's DNA, where the virus has embedded itself—and Charpentier and Doudna figured out how a bacterium's immune system accomplishes that feat. They then designed a process to chemically reprogram that mechanism to cut out any stretch of DNA at a predetermined spot in a bacterium's genome and replace it with a molecule of the scientists' choosing. (They shared the Nobel Prize in Chemistry in 2020.) Other researchers soon developed methods to edit the genomes of any other organism, including ours. (Zhang Feng at MIT deserves special recognition.)

Yes, CRISPR is almost like magic.

Other techniques existed for editing DNA before CRISPR, but they were much less precise and could take months to prepare. CRISPR was a generalized, programmable method that was easily repeatable and cut the time to hours—or even minutes. The Nobel committee called the CRISPR advance "epoch-making" and dubbed it "a tool for rewriting the code of life."[36]

Already, the applications are wide-ranging. CRISPR is being applied to major staple foods in Africa, such as wheat, cassava, and banana, to help them resist disease.[37] Another group showed that CRISPR can snip

---

* CRISPR/Cas9 is short for "Clustered Regularly Interspaced Short Palindromic Repeats and CRISPR-Associated Protein 9." This clunky phrase was chosen more to fit the acronym than the other way around, according to Francisco Mojica, the Spanish molecular biologist who coined it. He thought that "CRISPR" sounded friendly and that the dropped "e" gave it a futuristic sheen. His wife thought CRISPR was a great name for a dog.

out a family of viruses in pig DNA and potentially increase the opportunity to use pig organs for human transplants. A third group has developed a CRISPR-based treatment that appears to fix the genetic mutation responsible for muscular dystrophy in dogs.[38] And CRISPR-enabled technology is poised to revolutionize medicine: Researchers are developing CRISPR/Cas9 therapies for a wide range of diseases, including inherited blood and eye diseases, neurodegenerative conditions such as Alzheimer's and Huntington's disorders, and even non-inherited diseases such as cancer and HIV.[39]

Now, think more broadly: Imagine what's called a gene drive, a genetic engineering approach designed to spread a gene across an entire species. A gene drive could potentially spread an advantageous trait—or could even wipe out an entire dangerous species.[40]

A gene drive tool changes the genes of a single creature in a way where those genes become dominant, are passed on to all offspring and, eventually, are spread to the entire species. A gene drive could alter female mosquitoes to not bite—the males don't bite, so the alteration would end malaria. A gene drive could produce rats that only have male offspring, eliminating a threat to, say, the native bird and turtle populations of Galapagos. Gene drives could fight invasive crop pests like the fruit flies that eat up the raspberry patch of one of your authors every season, no pesticides required.

Actually, you don't have to imagine any of these things. All these possibilities have been demonstrated. CRISPR lets us alter both individuals and entire species.

We're not saying we should make any of these fundamental changes. Ecosystems are remarkably complicated, and there are loads of examples of attempts to handle a pest by introducing a predator for that pest—only to find that the predator created many more problems than it solved. Even if you go after something as clearly vile as rats, well, what animals feed on the rats and will now struggle for food? What animals feed on the animals that feed on the rats? What else did the rats feed on, besides the eggs of the species you want to protect? And so on.

We favor slow changes so that we can see what the full ramifications turn out to be for an ecosystem. We're taking great strides and baby steps at the same time. And many of our steps are in the dark—or, at the very least, the fog.

While we still have much to learn even about the meaning of the genomes we can read, genomics already provides hope for addressing a number of diseases caused by variation in a single gene. These diseases include sickle cell anemia, cystic fibrosis, Huntington's disease, and Duchenne muscular dystrophy—debilitating diseases that afflict some 400,000 people just in the U.S. CRISPR is helping researchers to better understand these diseases, and a number of therapies are currently in the midst of clinical trials for treating and even curing them.

Eric D. Green, who heads the National Human Genome Research Institute (NHGRI), a part of the National Institutes of Health (NIH), wrote in *Wired* in late 2020 that he believes genomics will provide a platform for discovery that broadly accelerates the pace of biology research.[41]

> "A lot of times people hear CRISPR and think of therapies for people. But by far the bigger use is at the bench. With CRISPR, we can make edits to little pieces of DNA that never go into a person—they go into cell lines or bacteria, which then get tested to see if those edits have functional consequences. The combo of genome editing and genome synthesis methods getting better, coupled with better and better computational tools, is really going to change the pace of biological discovery. Right now, we rely on one paper being published about one genomic variant to give us one drip of information at a time. That doesn't scale.
>
> So we've got to get to a point where we're making millions of changes, generating massive amounts of data, and then hopefully we can use AI to train computers to look for patterns. At that point, we won't even have to do the experiments, because we can make predictions about what a mutation means based on the last 1,000 times we've done this. Going forward, those are the sorts of tools that might make the difference."

Think of his approach as science in hyperspeed. Progress in genomics rides on the coattails of the Laws of Zero in computing, communications, and information. If Green is right that research can increasingly move from the lab bench to the computer, then progress can happen at the speed of electrons. That means the Laws of Zero can exponentially

amplify the capabilities in genomics, enabling a platform for discovery about the workings of life itself.

And who knows where that takes us?

In medicine, almost every new drug and vaccine is already based on genomics,[42] which is also a foundational tool in almost every field of science related to biology, including agriculture, environmental studies, health, and zoology. So, the Law of Zero for genomics will exponentially amplify science and engineering's impact over the next half century to a degree that will likely surpass the impact of the computing platform it's built upon.

Just in the next five to 15 years, Green, Collins (the director of NIH), and their colleagues predict genomic testing will become as routine as complete blood counts and will guide prevention, diagnosis, and therapy. They expect that the biological function(s) of every human gene will be known and that studies involving analyses of genome sequences will be so routinely available they'll appear at school science fairs.[43, 44]

The sorts of techniques and computing power that are opening up genomics will allow for other "-omics" with extraordinary potential, too—proteomics, metabolomics, and other fields that will provide deep understanding of how our cells function.

One limiting factor for genomics lies in the difference between a genotype and a phenotype. A genotype is the genetic characteristics of an organism as detailed by its genome, while a phenotype refers to the actual physical characteristics of that organism. It's analogous to the difference between a blueprint for a house and the actual house itself. The physical characteristics of an organism are determined not just by the genetic blueprint described in the genome but by the complex interaction between an organism's many genes and environmental factors beyond the genome itself.* This complex interaction, known as epigenetics, very much affects health, albeit in complex ways. Even when we have all the data in front of us, as we do with many cancer genomes, the epigenetics are so complex that we can't yet decipher the diseases.

---

* The Department of Veterans Affairs (VA), with help from Booz Allen, has a program doing exactly this kind of genomics/epigenetics work. The goal of the program is to sequence the genomes of 1 million vets and match them to the 30-plus years of phenomic data contained in the VA's electronic health records. The work, which created electronic health records decades ahead of the private sector, provides a treasure trove of phenomic data.

But the Law of Zero on genomics, building on the Laws of Zero on computing, communication, and information will steadily advance our understanding—at an ever-accelerating pace.

We can also envision harnessing the power of genomics to create healthier foods; to eliminate the microbes that cause disease; to eradicate the most dangerous pests; to correct the genetic errors that cause disease; and to do all of the above in an ethical and equitable manner with a deep understanding of the implications of our choices.

We are truly writing in the language of life—and we're getting better at an exponential rate. Mendel would be proud. Stunned, but proud.

PART TWO

THE FUTURE HISTORIES

"History will be kind to me, for I intend to write it myself."
—Winston Churchill[*]

Churchill was right. History will be kinder to us if we take the time to write it ourselves —especially if we do so *before* it unfolds, not after.

Every desirable (and undesirable) future scenario in this book depends on a host of complex interactions, and realizing our Future Perfect will require getting everyone on the same page for the challenging transition to it. The best way we've found for doing this is by imagining an idealized version of a future that's years out. Then, from that vantage point in the future, we craft a "history" that lays out how we got there from here. Thus, our name for these narratives: "future histories."

Devices like our future histories show up in many settings as ways of helping people jointly construct a vision and start implementing it. When Amazon begins work with a potential partner, it often starts by jointly producing a mock press release "announcing" a deal. Only when the two sides establish the broad outlines of the desired future do they start negotiating the details and working toward it. Maybe our favorite example reaches back to 1296, when the Catholic church in Italy laid out plans for the glorious *Il Duomo* in Florence and began construction—without knowing how to build the dome that gives the *Cattedrale di Santa Maria del Fiore* its famous nickname, but confident that the expertise would be there when needed.

---

[*] This is a common paraphrase of the sort of thing that Churchill said many times. For instance, toward the end of World War II, a British admiral said that the verdict on an operation would depend on who wrote the history, and Churchill replied that "he intended to have a hand in that." [*Churchill: Walking With Destiny*, by Andrew Roberts, Viking, 2018, p. 835] In a debate on foreign affairs in 1948, Churchill suggested that all the parties "leave the past to history, especially as I propose to write that history myself." [*Churchill*, p. 908]

A competition to design the dome was eventually launched in 1418, by which point understanding of architecture had, in fact, advanced sufficiently, and Brunelleschi completed the magnificent cathedral in 1436.

As we've said, future histories aren't meant to predict the future. Rather, our future histories focus on the outcomes we want to achieve. They can't be untethered, pie-in-the-sky, wishful thinking. We all want our team to win the Super Bowl every year, but it simply won't happen. (Yes, we realize there may be a Tom Brady exception.) Instead, our future histories focus on the outcomes we believe are ***achievable*** within the allotted time.

We'll ask: What would it be crazy for society not to have in 30 years? What big problems can the exponentials help us solve in that sort of timeframe? We picked a 30-year timeframe because that's so far in the future we don't have to worry (yet) about how to get there. At the same time, 30 years is close enough we can realistically envision what might be technologically possible, with enough foresight and effort—the scientific and technological starting points for much of what can be applied at scale in 30 years already exist today. That vision can then guide estimates of how much progress needs to be made by the halfway point, which, can, in turn, allow for the sort of five- or 10-year plan that's a common way of informing long-range strategy. Typically, those early investments are small, but you have to take that initial step so you can be ready for the next one and the one after that… and can be prepared to take full advantage when the exponentials kick in 10, 20, or 30 years.

It's certainly fair to worry about how we can possibly take the huge steps by 2050 that we'll lay out as goals for the Future Perfect. But allowing those worries to enter the process too early can severely constrain imaginations, and we might end up with incremental strategies that completely miss out on the future. Thinking bigger is almost always better. Kodak, the company that invented digital photography, spent decades taking baby steps toward digital and eventually went bankrupt defending its film and paper-based business. Incrementalism is why the original AT&T, which drove progress in computing, communications, and information for decades, couldn't make a successful transition from analog, circuit-switched, and wired phones to the world of digital, packet-switched, and networked mobile communications in the 1990s and 2000s and has had an up-and-down record since. Incrementalism is why

many of today's business giants won't make the transition to our more perfect future of 2050.

But *you* will!

Future histories aren't encyclopedic blueprints of a desired future state. As much as we'd love to have a concrete vision of 2050, there are simply too many variables to produce a fully realized projection of the world 30 years out. So, rather than a grand unified field theory of the future, we're going to sketch out some of the defining features. We'll illustrate with examples that, while they're already in use, are so far ahead of the game they may read like science fiction. (In our vignettes dated from 2035 and 2050, we'll use some names of companies and individuals that you'll recognize, but, obviously, any "quotes" from those companies and any individuals as well as the actions we describe in the future are figments of our imagination; assume any names you don't recognize are invented to make for a better story, but any events we describe as having occurred in the present day are real. You'll have to be a little careful, but we've tried hard to reduce confusion.)

Future histories fulfill our human need for narratives, taking abstract capabilities and visions and making them real in ways that let people internalize them and get excited. Future histories help people understand how they can contribute—how they will contribute. People can understand timing issues and see how efforts will build. People can also focus on the threats to their vision that, as a group, they must fend off. These threats may no longer be the saber-toothed tigers that stalked our distant ancestors, but they are still very real obstacles. We hope future histories can unite us as we face the inevitable challenges ahead.

In the next several chapters, as much as possible, we'll infuse the future histories with systems thinking. In other words, we won't just describe the technological breakthroughs that are coming but will do our best to show how they'll play out in much broader systems. For instance, while some proponents of electric vehicles tout the fact that no pollution comes out of tailpipes, our broader systems view will note that the electricity for the batteries largely comes from fossil fuel power plants; that the metals used in batteries and many electronic components are the product of a mining process that causes considerable damage to the environment and comes from countries many other countries would rather not support; and so on.

We're pleased to see that some industries are already starting to take more of a systems view. Historically, consumer products companies, for instance, have packaged their goods and then left it to consumers to figure out how to dispose of the debris. They're now realizing—under some pressure—that they need to consider the full life cycle of their products and come up with biodegradable packaging, a recycling process that goes far beyond what is happening today, or something so that we don't just keep adding landfills or expanding the 80,000-ton Great Pacific Garbage Patch. Nordstrom encourages customers to bring in beauty product packaging for recycling. MAC gives customers a free lipstick in return for a certain number of empties. But industry doesn't have a great track record on systems thinking. Companies optimize the performance and the cost of their piece of a system while not worrying about the whole.

The effect has been to create what Alan Kay calls "Myopialand" and to push to the future costs that are being incurred today.* Energy generation probably provides the best example, as the world has spent the past two centuries-plus producing "cheap" energy from fossil fuels and leaving future generations to deal with the costs of the environmental damage and to find a way to get the planet back on track. Swedish scientist Svante Arrhenius figured out 120 years ago how to calculate the effects of atmospheric carbon dioxide on the temperature of the planet and concluded humans were causing global warming, but warming was never assigned an economic cost, even as calculations of the cost have become increasingly precise over the past 60 years, so little was ever done. We'll try to be as careful as we can about weighing all the costs and all the prospective benefits in our future histories—though we acknowledge that experts in the areas we touch on will be far more precise than we are here and that, even for experts, it can be hard to predict all the interplay among forces in an ecosystem.

We won't write future histories for all the areas that we think are important and that will see massive change in the Future Perfect—we'd wear ourselves out, and we'd wear you out, too. But we'll cover several

---

* The intriguing sci-fi novel *The Ministry for the Future* by Kim Stanley Robinson builds on the idea of an international ministry set up to guard the interests of future generations against excessive climate change. While plenty of chaos ensues, Robinson describes the book as a hopeful "future history."

that we believe are key and hope we inspire others to use the model to tackle other critical issues, such as education, food, and shelter.

Like the Apple Knowledge Navigator video that helped produce the iPad some 25 years later, we'll include factors that should be revolutionary and will package them as neatly as possible. But, like that video, we won't presume to show all the changes that will ripple out from the breakthroughs. We'll count on you—and a host of other smart people—to figure out the rest.

Think of this part of the book as Future Perfect: Some Assembly Required.

Sound like a plan? Let's get started.

PREVIEW
UPGRADE

CHAPTER 11

The Future History of Climate

The Model City That Shaped Climate Hope

BELMONT, ARIZ., December 15, 2050—Swedish Prime Minister Greta Thunberg addressed the crowd today at the 25-year anniversary of the opening of Belmont, the model city near Phoenix.

Speaking via VR conference to avoid air travel, Thunberg played off the title of the blistering speech on climate change she made as a teenager to the United Nations in 2019. In that speech, titled "How Dare You?", Thunberg reprimanded politicians. She said, "You have stolen my dreams and my childhood with your empty words" about reversing climate change while "entire ecosystems are collapsing. We are in the beginning of a mass extinction, and all you can talk about is money and fairy tales of eternal economic growth." Today's speech was titled, "Dare We Hope?", and singled out Belmont as an example of the enormous progress that has been made on climate issues in recent decades, because of cross-sector developments in energy, transportation, industry, real estate, agriculture, and consumption.

"There is much more we have to do," she said, "but today I want to celebrate the reemergence of hope."

Belmont, with its 200,000 inhabitants, roughly the size of nearby Tempe, has gone well beyond carbon-neutral to be carbon-negative,

based on the profusion of power generated by clean sources. Belmont exports its excess power down a trunk line to Phoenix, reducing Belmont residents' energy bills while helping the nearby metropolis almost eliminate its own carbon footprint.

There is a large wind farm on the edge of the city, and solar is everywhere. Panels are on rooftops, carefully hidden from view. Even rooftops and windows are coated with photovoltaics. The wind and solar are complemented by a series of small nuclear reactors that provide a steady baseline of power. The molten-salt, thorium reactors, about the size of an old-fashioned water tower, are located near Belmont's manufacturing center, whose 3-D printing capabilities supply almost all of the city's requirements and whose peak power needs can stress the local solar and wind resources.

Bill Gates, the founder of Belmont, had made his second fortune—or is it his third?—when his early backing of small thorium reactors generated a return of more than $100 billion as they were adopted worldwide. The reactors not only power cities but provide so much energy that they are being used to extract carbon dioxide from the air, combine it with hydrogen, and produce carbon-neutral, renewable fuels, which have become another trillion-dollar industry worldwide.

All the cars are electric, and no one is burning anything to generate electricity in Belmont, so those deep blue desert skies are as clear and crisp as they were centuries ago.

Visitors eventually realize that another feature of older cities is missing, too: power lines. Homes generate so much power and have such battery storage that they're designed to be energy-independent. For backup—and to provide a way to contribute excess electricity for other homes or for export—a mesh network connects each house to its neighbors and eventually to a grid-scale battery at the center of each neighborhood's micro grid. (Although the grid-scale batteries were, for a long time, too expensive and lacked enough capacity to be economic, Gates subsidized them in the city's early days to simulate what micro grids could look like, and the batteries' capabilities eventually grew into the design.) The batteries also connect in a loose web to provide backup power to homes but carry

little electricity, given the near-self-sufficiency of each house and each neighborhood, so it was easy to bury all wires underground.

The insides of homes in Belmont also feel different, mostly because of the exceptional focus on energy efficiency. The homes in Belmont use materials that allow for a radically different approach to air conditioning—they change chemical composition or shape as they absorb heat and cool a room, then are returned to their original state by applying electricity. The materials are built into the architecture in strategic spots, where they can take heat out of the air during the day and be "reset" each night. No need for loud AC units or for all the ductwork that homes used to use to distribute cool air. Ducts aren't needed for heating, either. A series of small, electric radiators take care of heating needs, so construction costs are much lower than they used to be.

Residents of Belmont—sometimes referred to locally as "Billmont," after the founder—have more money in their pockets because the exorbitant electricity bills they used to pay to run air conditioning in the summers near Phoenix (where highs can easily hit 115 degrees) have disappeared. The nearly limitless access to energy has also let Belmont solve one of the thorniest problems in the Southwest, water, which is simply pulled out of the air for most household needs.

Borrowing a concept proven in Japan's Woven City, the streets of Belmont are split into three zones: one for cars, which are mostly autonomous; one as a promenade shared by pedestrians and slower forms of personal mobility, such as bikes and scooters; and one as a tree-filled parkway for pedestrians only. This multimodal transportation system design alleviates several of the negative side effects of car-centered city planning: sedentary lifestyles and expensive transport. Just a few decades earlier, 40 percent of trips by car in the U.S. were for less than two miles, in large part because the streets were so inhospitable to pedestrians and cyclists. There are no such impediments in Belmont, and the residents are much healthier because of the increased physical activity. When residents don't want to walk or bike, they can hail an AV taxi service that's sized for their needs and that they can use at a much lower cost than owning their own car.

"As you look around your city," Thunberg said at the anniversary celebration, "you can see Winston Churchill was right when he said, 'You can always count on Americans to do the right thing—after they have tried everything else.'* America got off to a slow start on climate change and led the world in science deniers, but the country recognized the power of the Laws of Zero and has now led progress around the world for many years."

She ran through a list of achievements:

- Globally, the goal of reaching net-zero carbon emissions is within striking distance as the Laws of Zero continue to drive down the cost of clean energy and carbon removal.
- Economies have become so much more efficient that energy intensity—the amount of energy required to produce a dollar of GDP—has declined by between 50 and 75 percent in all countries around the globe. The drop reached 80 percent in India and China, mammoth economies where the most progress was needed.
- Traditional fossil fuel companies long ago realized their businesses had become unattractive. Large investors such as pension funds, insurance companies, endowments, and sovereign wealth funds pulled out of the companies because of concerns over climate change, and the companies saw better opportunities in adjacent areas. Many companies managed the transition risks and transformed into businesses focused on carbon capture, chemicals, renewable fuels, and geothermal drilling.
- As investors and fossil fuel companies shifted their focus toward opportunities in clean, sustainable energy, governments, especially in the U.S., yielded to public sentiment to pursue climate-friendly energy policies.
- The rapid infusion of new energy jobs has completely overwhelmed the loss of jobs in the old energy sector.

---

* Like many quotes attributed to Churchill, these words don't appear in any of his voluminous writings, and there's no evidence he actually said them. But, as Sen. Mark Warner, who is especially fond of Churchill and the quote, said, after being corrected about the attribution, "If Churchill didn't say it, he should have."

- Measures of equity in health, wealth, and happiness have improved globally, as the green transition provided a springboard to address poverty in developing countries and structural racism and social injustice in the developed ones.

As Thunberg ended her hopeful keynote, Gates, now 95 years old, said he hoped that she would soon visit Belmont in person, and with a clear conscience.

"We're making so much carbon-neutral fuel in Belmont that we don't know what to do with it all," he said. "I'll send you a jet, and you can have all the fuel you need."

Climate is the most dramatic illustration of how we're not trying to predict the future but invent it. We want to find a hopeful alternative. Sadly, if we were forecasting, the most likely future of our climate is a continuation of the long history of insufficient action in the face of ever-stronger scientific evidence of human-driven change and impending disaster. It's all the more critical, then, to articulate a less likely—but still achievable—future history of climate we can collectively work toward.

We think it would be crazy if we didn't significantly slow global warming and mitigate the worst effects of climate change by 2050.

The goal on climate change is stark. The federal government's recent, self-described "authoritative assessment of the science of climate change,"[115] the Climate Science Special Report (CSSR), said that, globally, we need to go from the roughly 51 billion tons of carbon emissions a year we're emitting today to net-zero emissions by 2050.* If we don't do so, the consequences will be disastrous for our kids and their kids—rising sea levels; extreme flooding and storms; heat waves; wildfires; droughts; devastated farming, fishing, and other food production; flooded cities and infrastructure; mass migration; resource wars; and

* The exact tonnage of global emissions is hard to measure; estimates range as high as 60 billion tons per year. When we refer to carbon emissions in this chapter, we use the estimates by Bill Gates in his recent book *How to Avoid a Climate Disaster*. The exact number is less important than the acceptance that the amount of carbon emissions is huge and that we have to eliminate all of it.

more. We're already seeing some effects. Try to think of the last time you managed to go on Twitter and didn't see an image of a wildfire, massive flooding, or even perhaps the ocean on fire.

To avoid climate disaster, we first need to start by getting to net-zero emissions in five types of human activities that contribute most of our carbon emissions: how we plug in, how we make things, how we grow things, how we get around, and how we keep warm and cool. (The relative contributions, as of 2019, are shown in Table 1.[116])

To make things all the more difficult, we have to hit a quickly growing target.

According to the World Bank,[117] about 74 percent of the world's population live in "middle income" countries. A further 9.2 percent live in poorer countries. All 6.3 billion of those people are working to share in the living standards enjoyed by the 1.2 billion people living in countries with "high income." And many more will join those aspirants: The UN estimates world population will grow by 1.9 billion between 2020 and 2050, with all of the growth happening in middle- and low-income countries.[118] That means more than 8 billion more people wanting more things.

That's a lot of people. And, as things stand, it'll result in carbon emissions dramatically rising, not falling. Growing food to feed all these people increases carbon emissions. Providing clean water and sanitation to them increases carbon emissions. Building homes for them increases carbon emissions. You get the idea. In effect, the world is building the equivalent of another New York City—every month. That means our planet will have added nearly 350 New York Cities between when we're writing this in 2021 and 2050. That's our goal date for slashing emissions

TABLE 1. Current Carbon Emissions

Current Emissions (2019)	CO_2 (Billion Tons)	Percentage of Total
Plugging in (electricity)	13.77	27%
Making things (industry)	15.81	31%
Growing things (agriculture)	9.69	19%
Getting around (transportation)	8.16	16%
Keeping warm and cool (shelter)	3.57	7%
	51.00	**100%**

to net-zero—and there's a lot of momentum taking us in the wrong direction.

The Laws of Zero are already enabling solutions that can bend the carbon-emissions curve. As we've seen, solar- and wind-generated electricity sources are becoming cheaper to build and operate than existing coal plants are to operate. And transportation is rapidly switching to electricity, which will increasingly come from clean sources. On their own, those Laws of Zero on energy and transportation won't get us to the answer, but the laws on computing, communication, and information give us a platform for innovation in an array of other areas. Those laws at least give us hope.

To succeed, the laws will need to enable a six-pronged strategy:

- Get all electricity from net-zero sources;
- Electrify everything possible—and develop clean fuels to do everything else;
- Introduce efficiencies that lower energy needs and emissions;
- Make scientific breakthroughs to address current gaps;
- Develop technologies that make it feasible to pull massive amounts of carbon from the air; and
- Do all the above… at a cost less than or equal to any carbon-emitting alternatives.

So you can see how close we can get to net-zero emissions based on current trajectories—and see just how sizable the gaps are that still need to be filled—we'll go through all six prongs in some detail. There's a cartoon we like where two professorial characters are standing in front of a chalkboard full of complicated equations. One points to a spot in the middle of the blackboard where the other has written, "Then a miracle occurs." The caption says, "'I think you should be more explicit here in step two.'" With climate change, we acknowledge a bunch of near-miracles need to occur. We're going to try to be as explicit as possible about where those need to happen so that all you future historians have a clearer picture on where you might want to get to work. Here's an incentive: Any one of these near-miracles would both help save the planet and generate a fortune the likes of which few have ever seen.

Net-Zero Electricity

Here's where the Laws of Zero really shine.*

As we discussed in the future history of electricity, we think it'd be crazy not to have clean electricity available to everyone, everywhere, in abundant and affordable quantities in the Future Perfect. Zero-carbon sources, mostly in the form of solar power, wind power, nuclear power, and hydropower, already account for 37 percent of all electricity generation. Getting those sources close to 100 percent by 2050 would eliminate a large chunk (27 percent) of the current problem for emissions and would mean clean sources would fulfill the many new demands for electricity.

But getting to total clean energy is far easier said than done. As we've noted, the current grid is a major problem. Zero-carbon electricity has to be reliably and affordably delivered where it's needed, when it's needed, and in the amounts that are needed, and the current grid isn't up to the task. We'll need to build long-distance transmission lines to take power from sunny and windy regions to other areas. We'll need major advances in batteries and other technologies to store enough electricity for use during nights and cloudy, windless days and to deal with the seasonal differences in sunshine and wind.

As drastic as these advances may seem now, there's a heated debate on whether they would even be enough. Two of the richest and most forward-thinking people in the world are on opposite sides of this debate: Elon Musk is among the optimists, and Bill Gates is among the skeptical. While Musk believes advances with solar, wind, and batteries will meet our needs, Gates (who supports the adoption of renewables as quickly as possible) argues breakthroughs may also be needed in nuclear fission and fusion to fill gaps in the service that renewables will be able to provide. (We think the stakes here are so high and the timing so urgent that we need to go full speed ahead on all fronts—just in case.)

Fortunately, tools enabled by Laws of Zero in computing, communications, and information will provide a platform for innovation at

---

* Tragically, technology to date has been a key enabler of global warming and impending climate disaster. The rise in atmospheric carbon and the resulting impact on the climate stem directly from the harnessing of fossil fuels that enabled the industrial revolution, warmed and cooled our homes, brought us the marvels enabled by fast and cheap transportation, fertilized our soil to grow things, and underpinned most aspects of the tremendous advances in standards of living over the past two-and-a-half centuries.

unprecedented speed. Tests of new materials, new approaches to building and managing the grid, and so on used to require painstaking work in the physical world. But those efforts can increasingly be done based on models and simulations, essentially becoming software problems that AI can tackle. The work can be done on computers over periods measured in seconds, minutes, and hours, not in months, years, and decades.

For example, multiple groups of researchers are now using sophisticated computer simulations to develop alternative strategies for transforming the U.S. grid. They're starting with detailed models of all existing power grids, along with detailed weather and usage patterns, and are then simulating different placements of generation and transmission capabilities. The researchers looked at current plans, including some considered ambitious, that would cut emissions by six percent by 2030 and have created more detailed options that could reduce emissions by 42 percent by the end of the decade.[119] The researchers have made their tools and models publicly available so others can stress-test the designs and explore alternatives.

Electricity Everywhere

Once we have all that net-zero electricity (we hope), we have to use it to replace fossil fuels in as many applications as possible.

Transportation

Transportation contributes about 16 percent of total global carbon emissions, so converting it, alone, to clean power sources would be a major advance. As we've explained, we're on the cusp of having electric vehicles that are cheap enough and have enough range that they'll initiate the phaseout of internal combustion engines. The challenge will be scaling: We'll have to adopt clean electric vehicles everywhere possible and do it fast enough to replace all existing dirty vehicles by 2050.

That will be hard. (Everything about climate seems to be.) At current rates, it takes about 15 years to turn over an entire fleet of vehicles.[120, 121] So, starting in 2035—15 years before our deadline of 2050—all new cars would need to be net-zero. Forecasters aren't optimistic, however. As we write this in 2021, analysts project electric vehicles will make

up just one-quarter of new sales by 2035. By 2050, electric vehicles are projected to make up only 60 percent of sales, and projections are that most vehicles in use will still be powered by fossil fuels.[122]

Still, some major companies and governments suggest the forecasters may be too pessimistic. General Motors, for example, has announced it will launch 30 electric vehicles by 2025 and will phase out all its gas- and diesel-powered vehicles by 2035.[123] Volvo announced it will stop selling fossil fuel-powered cars by 2030.[124] Ford and Jaguar said they would move to all-electric in Europe by 2030.[125] On the regulatory side, California has set a net-zero target for new cars and trucks by 2035.[126] The UK plans to ban the sale of new gas and diesel vehicles by 2030, while Norway has set a 2025 target.[127]

The Laws of Zero also suggest we may get closer to the 2050 goal than those naysaying forecasters currently predict—even professionals have trouble seeing the effects of the exponentials at work in the Laws of Zero. But some other things will have to happen, too.

There will need to be a virtuous circle of shared, autonomous electric vehicles. As we wrote in the future history of transportation, AVs enable consumers to forego the huge fixed cost of owning a car and, instead, bear the variable cost of an autonomous car service that provides transportation on demand. The potential market here is enormous. Early business modeling shows such services can deliver handsome profits while charging consumers a lower cost per mile than the per-mile cost of car ownership. Such services would grow rapidly, given the economics for both providers and customers, and all AV platforms will be electric because of the requirements of all the sensors in the vehicles. At the moment, many individuals are reluctant to buy electric cars because their up-front cost is higher than for those with internal combustion engines,* but these car services will be operated by large commercial fleet owners (including the likes of Waymo and General Motors), and they won't suffer the same sort of sticker shock that might scare off individual

* Operating costs for electric vehicles are lower than for those with internal combustion engines, and the lifetime cost of an EV can be far lower, but the crossover point at which an EV becomes less expensive has tended to be at least a year after purchase, and possibly much longer. The actual calculations obviously depend on a host of variables, including any government incentives for buying an EV, the model purchased, the miles driven, and the costs for gasoline and electricity.

consumers. Thus, electric vehicle technology could be adopted earlier and at price points higher than might attract consumers.[128]

Autonomous electric vehicles will also need to evolve into dramatically new forms. As we've discussed, fleet-level car sharing will allow for matching vehicles to particular trips rather than vehicles being one-size-fits-all. Because most car trips are short ones involving one or two people, most cars in a shared fleet could be smaller, simpler, and cheaper than those most of us own now. Such simplicity in cars would also reduce the traditional competitive advantages that stem from automakers' ability to manage complex supply chains and integrate thousands of parts. Simpler cars would also reduce the necessary engineering expertise and capital costs, two barriers to entry that have protected automakers from new market entrants. All these factors would invite more competition and innovation, enlarging consumer choice and accelerating adoption.

Governments will need to speed the transition to electric vehicles. Nations can, for instance, provide investment incentives and production mandates for manufacturers, purchasing incentives for consumers, and investments for the electric grid and for charging infrastructure to support electric vehicles. Nations can also create disincentives for the use of fossil fuels. While interested parties always push back when governments try to pick winners and losers, there's an international competitive dynamic here. Governments want to make sure that their countries' automotive industries remain competitive as the market shifts to electric vehicles and AVs.

Markets will have to do their job—as they generally do. Investors are already betting on the rapid transition to electric vehicles and, as a result, are providing tremendous amounts of capital to the companies most likely to drive the transition. Investors will continue to reward pioneers with promising ideas, as they have Tesla, and that should drive us closer to electrifying transportation by 2050.

Pulling all the right levers for cars, SUVs, motorcycles, and light-duty commercial trucks and buses by 2050 covers about two-thirds to three-fourths of all transportation-related emissions. But long-distance trucks, cargo and cruise ships, and planes could prove difficult to shift to electricity because of the weight of the batteries. For these applications, we'll need price breakthroughs in net-zero fuels like biofuels or hydrogen for trucks and planes (which currently cost two and a half to six times more) and

perhaps in nuclear power for ships. The good news for shipping is that 40 percent of all cargo ships are devoted to carrying fossil fuels today, and that tonnage will almost certainly no longer need to be transported.

Heating and Cooling

Another area ripe for clean electrification is in heating and cooling our buildings, which currently account for about seven percent of the global total of emissions.

Cooling is the easy part, as air conditioners already run on electric power. If we can't generate enough clean power by 2050, though, we're in trouble because the demand for air conditioners is growing so fast, and that pace will only quicken in a warming world.* There are about 1.6 billion air conditioning units in the world, and that number will more than triple to over 5 billion by 2050, according to the International Energy Agency.† At that point, just air conditioners will consume as much electricity as all of China and India do today.‡

Heating, in the form of furnaces and water heaters, are the fossil fuel burners in our homes and offices. Today, half of all furnaces sold in the U.S. run on natural gas. Worldwide, fossil fuels provide six times more energy for heating than electricity does. The good news is, for new construction, the cost of an electric heat pump (which both warms and cools) is less than the combined cost of a new gas furnace and electric air conditioner. But furnaces tend to last a decade or more, so it'll take a long time to move away from those already installed. To get to a goal of all-electric by 2050, we'll have to stop selling gas-powered furnaces and water heaters by 2035. For however many remain in operation after 2050, we'll still need alternative net-zero fuels.

---

* Lots of people in the Pacific Northwest and western Canada never thought they needed air conditioning but found themselves dealing with sustained temperatures well above 100°F because of the heat dome that formed repeatedly in the summer of 2021.

† The U.S. and Japan currently lead the world, with more than 90 percent of households already having some form of air conditioning, according to International Energy Association estimates. China is at 60 percent. By contrast, Mexico and Brazil are near 20 percent, and South Africa and Indonesia are below 10 percent penetration.

‡ In addition to carbon emissions because of electricity consumption, air conditioners also emit what are known as F-gases (because they contain fluorine), which cause 23,000 times the warming effect of carbon dioxide.

Industry

Industry and the general activity of making things account for about 31 percent of all carbon emissions today, so there's a huge opportunity here. Unfortunately, there isn't a straightforward transition to clean electricity.

Industrial emissions come from three sources: (1) the fossil fuels used to generate the electricity used by factories; (2) the fossil fuels used to generate the heat used in manufacturing processes, like melting iron ore to make steel; and (3) the emissions generated when the materials are made, such as the carbon dioxide released by the chemical process of making steel. We've already dealt with the generation of clean electricity. Greater challenges lie in the second and third sources of emissions.

Take cement and steel, which together account for 13 percent of annual global emissions. Their manufacture requires intense heat, about 2,000°F, to melt the limestone for cement and almost 3,000°F to melt the iron ore for steel. Using electricity to generate that sort of heat is far more complicated than just plugging into the electric grid. However, nuclear power or hydrogen might substitute for some of the fossil fuels that generate the enormous heat we use today.

Likewise, the chemical processes involved in making cement and steel emit carbon dioxide that has nothing to do with fossil fuels. Globally, we currently make about four billion tons of cement each year, and every ton results in a ton of carbon dioxide. We make about 1.8 billion tons of steel each year, and every ton results in 1.8 tons of carbon dioxide. Those emissions are on top of the ones produced while melting the limestone and iron ore; reducing or capturing these emissions will also require innovations beyond electrification.

Agriculture

Growing food accounts for about 19 percent of all global emissions, and clean electrification will only help a bit.

In agriculture, we're mostly concerned with methane and nitrous oxide, not with power sources. While the amounts of these greenhouse gases are small compared with carbon dioxide emissions, they're particularly dangerous. Methane causes, per molecule, 28 times more warming than carbon dioxide. Nitrous oxide causes 265 times more. Together, methane and nitrous oxide account for about 80 percent of the emissions due to agriculture.

Cows are the primary source of methane. Cows, goats, and other grazers are ruminants, meaning they can digest grass and other plants and grains most animals (including humans) cannot. But their digestive systems use a process called enteric fermentation that produces methane. Lots and lots of methane. The cows then release the methane into the atmosphere through what scientists call eructation and flatulence, or what our kids refer to as burping and farting. Each cow burps and farts between 160 and 320 liters of methane every day and, globally, there are about 1.5 billion cows.[129] Cows, alone, account for about four percent of global emissions. Cows contribute about half the nitrous oxide released into the atmosphere as their feces decompose, while pig feces contribute the other half.

Other major sources of agricultural emissions include deforestation and other land use, which together add up to three percent of global emissions. Fertilizers are responsible for about two and a half percent. And as much as one-third of all food produced globally is wasted.[130]

Electrification offers no simple solutions for any of these agricultural emissions, though other innovations hold promise. Pilot projects putting additives in cows' feed, derived from seaweed, have reduced their methane output by 50 to 90 percent.[131] Scientists are studying ways to reduce methane production through genomics and selective breeding. The many companies now developing artificial meat could also greatly reduce the size of cattle herds.*

Efficiency, Efficiency, Efficiency

In the 1960s, cautioning that federal spending had a way of getting out of control, Senator Everett Dirksen reportedly observed, "A billion here, a billion there, and pretty soon you're talking real money." Well, as our above cataloging of the vast and varied contributors of carbon emissions should attest: A billion tons of carbon here, a billion tons there, and pretty soon you're talking real climate change.

But the billions can be rolled back, too. Cyclists packing their panniers for their first road trips are cautioned, "If you take care of the

* While talk of artificial meat has led to claims that governments will outlaw hamburgers, there is also a growing eco-conscious food movement that could shrink the need for cows. So-called reducetarians are switching to oat milk and protein sources such as tofu to decrease their consumption of red meat.

ounces, the pounds will take care of themselves." If we make efficiency a key component of the Future Perfect, we can, bit by bit, drastically reduce the amount of carbon we either have to reduce or capture. The easiest ton of carbon to eliminate is the one you never produced.

Efficiencies must be gained in two key areas: energy and materials.

Energy Efficiency

A 2020 study found that energy efficiency policies and programs enacted over previous decades in the U.S. saved so much energy in 2017 that, without them, U.S. energy use would have been about 23 percent higher. These policies and programs included fuel economy standards, appliance and equipment standards, the Energy Star efficiency program, utility sector efficiency programs, and energy codes for buildings. For example, standards have reduced energy usage of appliances by 80 percent since 1980 (saving the average American household about $500 a year).[132]

A host of additional energy-efficiency options will be available by 2050.[133] For instance, efficient design of new homes and commercial buildings, including electrification and the use of renewable electricity, could cut their emissions by 80 percent.

Materials Efficiency

Although we'll need to make a lot more things by 2050, as the population increases and poorer countries race to improve their economies, we can use less material to make those things. We can also shift to using materials that involve fewer emissions.

For example, the International Resource Panel, an arm of the UN, has developed a number of efficiency strategies that could, by 2050, collectively reduce emissions by 80 percent for materials used in homes and 57 percent for materials used in cars.[134] These strategies can be deployed starting now, with existing technologies. Among them are: designing lighter buildings, to reduce the use of carbon-intensive materials such as steel, cement, and glass; using wood, a carbon-neutral source, instead of reinforced concrete and masonry; and improving the recycling of materials used in buildings and cars.

Scientific Breakthroughs (Where the Near-Miracles Occur)

Some of these needed breakthroughs will seem far-fetched, even impossible. But, as we've tried to convince you over the course of this book, the progress that will come by 2050 by following the Laws of Zero will, in many cases, feel like magic from the vantage point of 2021. In 30 years, some of these technologies will be routine—remember that the term "genomics" didn't even exist 30 years before the invention of CRISPR.

The breakthroughs we need to have happen to invent the future history of climate in 2050 fall into two categories: those in energy and those in areas that could significantly reduce carbon emissions.

Energy Breakthroughs

- Pumped hydro (water is pumped uphill to a reservoir when energy is available, then released downhill to a lower reservoir, through a hydroelectric generator, when power is needed)
- Thermal storage (a substance is heated when energy is available, then the heat is used to produce electricity whenever it's needed)
- Alternative fuels, including biofuels and hydrogen produced without emitting carbon
- Grid-scale electricity storage that can last a full season
- Geothermal energy
- Safe, modular nuclear fission
- Nuclear fusion

Carbon Emission Breakthroughs

- Zero-carbon cement
- Zero-carbon steel
- Zero-carbon plastics
- Plant- and cell-based meat and dairy
- Zero-carbon fertilizer
- Coolants that don't contain F-gases
- Carbon capture

Why do we believe these breakthroughs are possible? There are three reasons for our optimism.

The first is science.

The scientific discovery and invention platform enabled by computing, communications, information, and genomics allows "unbelievable leverage on the universe," as Alan Kay has observed to us. In every field, including mechanical, electrical, and biological systems, the process of hypothesis, testing, and learning provides access to boundless insight and is accelerated by computer modeling, analysis, and simulation tools. Individual learnings can be shared, stress-tested, and evolved through global collaboration and competition that is enabled by rich and near-instantaneous communications.

Science is now the standard method for developing everything, and it'll be the platform for making all the breakthroughs. These days, physical objects won't even be built until after extensive testing and validation via computing. And when they are built, the work can be done through computer-guided fabrication and 3-D printing. Like the technologies for reading and editing genomes, the Future Perfect computing platform can be used to invent things that were recently unimaginable and put them on an exponential improvement path.

The second reason is the urgency of self-preservation.

As the COVID-19 vaccines show—being produced and mass-distributed in less than a year as opposed to the normal 10 to 25 years—mankind can move fast when it must. To this point, the dangers of climate change have been ephemeral enough for many that it's been possible to defer action, but hurricanes, wildfires, derechos, and other disasters, combined with steadily rising temperatures, have changed the tone. Science and industry are rallying, and the pace will accelerate as the problems become more obvious.

The third reason is economics: the defense of value and the allure of new wealth.

BlackRock, the world's largest money manager, says, "Climate risk is … a historic investment opportunity." BlackRock says, "With the world moving to net-zero [carbon emissions], BlackRock can best serve our clients by helping them be at the forefront of that transition."[135]

BlackRock estimates doing nothing about climate change would result in a 25 percent cumulative loss in economic output over the next

two decades. An orderly "green transition" could avoid these losses. BlackRock also believes companies that react best to climate change will gain an advantage. For example, a chemical company that positions its product line for the massive adoption of electric vehicles could be a big winner, while an insurance company that doesn't adapt to the growing risk from physical climate damages will perform poorly.[136]

The investment firm has $8.7 trillion of assets under management that will back up its market assumptions, so BlackRock is sure to get the attention of CEOs and boards of directors. It's already asking companies to disclose their climate mitigation plans and provide data to track their progress. And markets always reward winners.

The top 10 steel companies in the world are collectively valued at (as of this writing) about $140 billion, and whoever develops the best way to make net-zero steel has a clear shot at much of that value. Net-zero steel might even expand the market, letting steel be used in ways it isn't now.

The same kind of opportunity holds true for companies leading in any of the other breakthroughs we've listed as being needed. We're in an age of transition where new ideas can uproot long-established businesses. Trillions are up for grabs.

Carbon Capture

You might have noticed we keep writing about getting to "net-zero" emissions rather than "zero" emissions. That's because even the most optimistic among us doesn't believe there will be some combination of scientific breakthroughs and societal fortitude that enables us to eliminate all carbon emissions by 2050. Some emissions will still happen, such as from the fossil fuels that still get burned and the carbon dioxide from the traditional cement recipes that still are used. Rather than letting those emissions stay in the atmosphere, we'll have to "capture" them. The emissions that we produce minus the carbon that we capture will net out to zero. Thus, "net-zero" rather than "zero."

Unfortunately, there might be a lot of carbon to "net" out. According to analysis by the UN, there is no plausible path to mitigating the worse effects of climate change without the successful capture of 100 billion to 1 trillion tons of carbon dioxide over the course of this century.[137] To put that in perspective, remember the world produces about 51 billion tons every

year at the moment. Once we get to net-zero in terms of our new emissions, there's hope carbon-capture technologies can be used to get to net-negative emissions, i.e., to extract the excess carbon pollution of past years and lessen global warming. (Spoiler alert: That possibility is a long, long way off.)

There are two general ways to capture carbon dioxide. One is at the industrial source, like power plants and cement kilns, before carbon dioxide is released into the atmosphere. The other method is to pull the carbon dioxide out of the air. In both methods, the captured carbon dioxide is compressed, transported, and buried in geologic formations, such as oil and gas reservoirs, coal seams, and deep saline reservoirs. There are also efforts to use the captured carbon to make things such as plastics, liquid fuels, fertilizer, and even cement.

We won't go into the technical details of how each way works except to say that both are technically understood, and small-scale efforts are in place. Because of cost, complexity, and policy challenges, however, both approaches fall into the "near-miracle" category in terms of the work to be done to reach global scale by 2050.

It's possible, for example, for industrial facilities to scrub carbon dioxide from their flue gas and reduce their life-cycle emissions by 55 to 90 percent. Yet, according to the International Energy Agency, only 30 million tons of carbon dioxide is being captured each year—just 0.3 percent of a reasonable goal for 2050.

Direct air capture is even more nascent. Carbon Engineering, a high-profile, Canadian-based company doing this, operates a proof-of-concept facility that captures 365 tons a year. It anticipates its first commercial plant will capture one million tons per year at a cost of between $94 and $233 per ton[138]—meaning the cost would be at least $1 trillion a year to reach a reasonable 2050 target for carbon capture.

Elon Musk has funded an XPRIZE competition for carbon removal to inspire and help scale efficient solutions to pull carbon dioxide directly from the atmosphere or oceans. After 18 months, 15 teams will be selected to receive $1 million to build their demonstration systems. To win the four-year competition, teams must demonstrate a rigorous, validated scale model of their carbon removal solution and the ability of their solution to economically scale to gigaton levels. $50 million would go to the winner, with $20 million and $10 million going to the second- and third-place teams.

Likewise, NRG and Canada's Oil Sands Innovation Alliance have sponsored a $20 million XPRIZE for developing ways to more effectively turn captured carbon into valuable products, thus helping enhance market mechanisms to support significantly more carbon capture. The concept, known as the circular carbon economy, is essentially turning carbon into a reusable material for making things, rather than just leaving it as the waste product of the industrial revolution. That's because, in theory, any product made with carbon from fossil fuels could be made with carbon captured from the air. Imagine turning the carbon dioxide captured from the chemical process of making steel into fuel for heavy trucks and planes. In addition to fuels, the long list of carbon-based products being adapted for captured carbon include cement, concrete and other construction materials, industrial gas and fluids, polymers, chemicals, carbon fiber, animal feed, and fertilizer.

Few believe using captured carbon for making things will put a major dent in carbon emissions any time soon, but it might help make carbon capture more economically viable. Every advance along that cost curve helps. Someday, we may even look back on these XPRIZEs in the same way we do about DARPA's grand challenge for autonomous vehicles—both may have helped to engage a generation of scientists and entrepreneurs and launched the exponential improvements necessary for this prong of our climate change mitigation strategy.

Far Lower Cost

Carbon emissions anywhere on Earth affect our collective atmosphere. So, to achieve a hopeful future history of the climate, we have to get to net-zero carbon emissions not just in the U.S. or in other countries rich enough to afford it, but everywhere. Imagine you were very poor; which would you choose: to be richer or greener? We'd love for everyone to be greener, but we all have to provide for ourselves and our families. That means we need to find alternatives that get us to net-zero that are at least economically neutral, or the world will tilt toward cheaper fossil fuels—and a climate disaster.

The cost difference between a zero-carbon solution and its carbon-dirty alternatives is known as a "green premium."[139] For example, if a gallon of standard jet fuel costs $2 and a gallon of zero-carbon biofuel

for jets costs $5, the green premium would be $3, or 150 percent. Some folks might be willing to pay that extra 150 percent for clean fuel, but the bulk of the global airline and air freight industries—which already operate on razor-thin margins—will have to stick with the $2 option. If someone could invent zero-carbon jet fuel for $2 or less, however, then there's no conflict in choosing it.

Green premiums currently hinder the adoption of most zero-carbon solutions. In addition to jet fuel, substantial green premiums exist for zero-carbon fuels for cars, trucks, ships, and heating. Plant-based meat substitutes cost a lot more than meat does. Direct carbon capture of industrial carbon emissions, like the making of cement, significantly increases manufacturing costs. And so on.

So we not only need science and technology breakthroughs, we have to make them much cheaper to drive global scaling and ubiquitous adoption.

• • •

Government policy will have to fit in the equation, too. As we've said repeatedly, we're not writing a policy book, but we as a society will need to cooperate to achieve a Future Perfect. Governments will need to facilitate that cooperation among different interest groups on climate policy—and policy can be even harder than science. Someone will have to live near that new, advanced nuclear reactor, and we'll need to sacrifice some habitat as we deploy more wind and solar. Communities are already battling over habitat—real estate developers want the land, as do advocates of renewables. In general, the dialogue in Washington, DC, suggests we're a long way from developing and implementing a thoughtful climate policy in the U.S.

If we can't get the policy measures right, economics may not save us. The idea that people will pay a "green premium" presupposes that people are eager to adopt a greener solution once it reaches cost parity. In fact, academic work and business history show that the diffusion of innovation happens fastest when the new solution provides a clear set of advantages, not just parity. Yes, climate change poses an existential threat, and concern is rising steadily, potentially pushing more of us to accept a "green premium," but it's hard to see why green jet fuel, for example, would appeal to airlines merely by reaching cost parity with

conventional jet fuel. After all, there's a great deal of operational risk in switching to a new fuel, and someone will get fired if the new fuel disrupts flight operations.

This means progress depends not only on producing some audacious technology breakthroughs but on having governments provide the right framework for helping society to cooperate as it nurtures and then absorbs them.

Despite the challenges we're facing, here's an example of how exponentials offer some hope:

Saving Billions, Making Trillions With Climate Solutions

Seattle, May 18, 2050—The Gates Foundation announced today that its endowment has surpassed $1 trillion in assets, even though the foundation has been spending and donating some $3 billion a year since its inception in 2006.

While the foundation was initially known for its efforts mostly on health-related issues, such as combatting malaria and eradicating polio, and while founder Bill Gates earned a great deal of attention in the 2020s for his years of prescient warnings about the sort of pandemic disaster that COVID-19 caused, the recent surge in the foundation's assets has largely come because of his work on climate change.

In particular, the surge has occurred because Bill Gates and his ex-wife, Melinda, donated so much of the fortune they based on a series of investments beginning in the 2010s that attacked carbon emissions. Those donations then made the foundation a magnet for funding by others who were focused on the cause.

"The foundation has played a significant role in helping us get so close to net-zero carbon emissions, seemingly in time to prevent the most severe problems of climate change we all worried about so much 30 years ago," said Andrew Tyler, the lead researcher for the UN Council on Climate. "Governments obviously spent more money, but the foundation seeded several key ideas and helped unleash the market forces that accelerated so many solutions."

Gates said the foundation expanded beyond its initial work on global health and poverty because he and Melinda saw that those suffering the most would also be hit disproportionately by the effects of climate change. They took the long view on climate, rather than seeking the sorts of quick returns venture funds and other investors typically pursue. The foundation invested only in companies that had the potential to eliminate one percent of global carbon emissions. The two also convinced a group of other billionaires and countries to invest alongside them.

The biggest successful investments included an early one in modular nuclear reactors, whose new design and growing safety record allayed the decades of fears about nuclear power, exacerbated by a few high-profile failures. An innovative design for grid-scale storage also proved massively successful. Those two investments alone now have nuclear power providing clean, baseline energy around the world and mean that solar and wind power can be deployed essentially without limit, with huge batteries capturing all the electricity they can produce.

Beyond energy, the Gates Foundation also championed startups that sparked breakthroughs in other areas needed to address climate change, such as better, less expensive cement and steel without CO2 emissions.

The returns for the former couple dwarfed what they earned from his first venture: Microsoft. While much of the potential from their more recent investments is still to be realized, the markets have assigned the companies valuations that mirror the sort of success that Elon Musk had in the early 2020s with Tesla.

The foundation has had a bunch of duds, too, of course. Few remember, for instance, some of the early investments in carbon capture. However, the duo parlayed these early learnings into smarter investments in the critical technology area, and direct air, carbon-capture facilities are scaling up fast because of their persistence.

"That's how investment portfolios work," Tyler said. "If they don't include a bunch of duds, then the aspirations aren't high enough to let the successes be so huge."

ABOUT THE AUTHORS

Chunka Mui is a futurist and innovation adviser who helps organizations design and stress test strategies focused on making the world a much better place.

Chunka is the best-selling author of four other books on strategy and innovation, including (with Paul Carroll) *The New Killer Apps: How Large Companies Can Out-Innovate Start-Ups* and *Billion Dollar Lessons: What You Can Learn From the Most Inexcusable Business Failures of the Last 25 Years*. One reviewer wrote that *The New Killer Apps* "absolutely nails how to and how not to innovate." *Kirkus Review* named it a book of the month selection and awarded it a coveted Kirkus Star for Excellence. *Inc., The Globe and Mail* and other publications named *Billion Dollar Lessons* one of the best business books of the year. In 2005, *The Wall Street Journal* named Chunka's first book, *Unleashing the Killer App*, one of the five best books on business and the internet.

Chunka is also a longtime contributor to *Forbes*, where he has published more than 200 articles and garnered millions of views.

He was previously the Chief Innovation Officer and a Managing Partner at Diamond Management & Technology Consultants (now part of PwC), a publicly traded multinational firm that pioneered the idea of digital strategy more than 25 years ago. He created and led The Exchange, an innovation learning community for senior executives (now PwC Exchange). He co-founded and directed Vanguard, a global research and advisory service that helped senior executives explore the intersection of strategy and emerging technology (now TTI Vanguard). Chunka started his professional career at Andersen Consulting (now Accenture), where he was an early member of that firm's AI group and co-founded its Center for Strategic Technology Research (now Accenture Labs).

Chunka holds a B.S. in computer science and engineering from MIT.

Paul Carroll has excelled at the highest levels of journalism for decades, while pushing the state of the art on business strategy and innovation.

For 17 years, he was a reporter and editor at the Wall Street Journal, where he wrote about information technology. The WSJ nominated him twice for the Pulitzer Prize, and he was a finalist once. He left to become a partner at Diamond Management & Technology Consultants, where he founded and edited a magazine that was a finalist for the National Magazine Award for General Excellence. For the past eight years, Paul has been the editor-in-chief at Insurance Thought Leadership, an affiliate of The Institutes that drives innovation in insurance.

He is the best-selling author of numerous other books, beginning with *Big Blues: The Unmaking of IBM*, published by Crown in 1993. In 2008, Paul and Chunka Mui published *Billion Dollar Lessons: What You Can Learn From the Most Inexcusable Business Failures of the Last 25 Years*, based on 20 researchers' two years of analysis of 2,500 corporate disasters. While Jim Collins looked at success stories and said, Here's how to be like those guys, *Billion Dollar Lessons* looked at failures and said, Here's how *not* to be like *those* guys. The *Wall Street Journal* review called the book "fascinating…, insightful and crisply written."

Paul was the writer on the National Broadband Plan, which the FCC submitted to Congress in 2010, and on a report that the Department of Energy produced later that year on a $36.5 billion innovation initiative funded by the Stimulus Act.

He and Chunka have founded a boutique consulting firm, the Future Histories Group, which stress tests corporate strategies. They have worked with senior management at numerous major organizations.

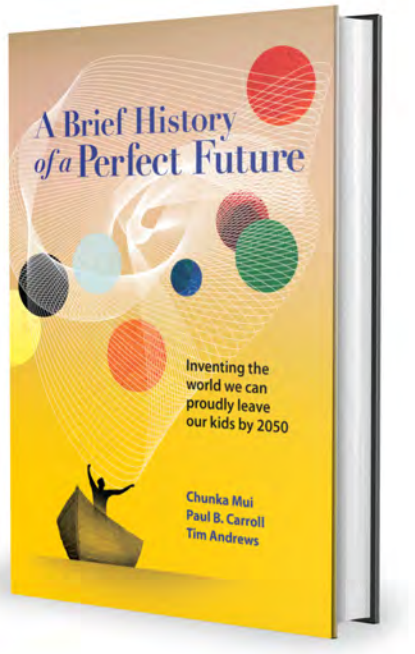
Paul graduated magna cum laude from Michigan State University's Honors College at age 19 and earned a master's degree in journalism from Northwestern University the following year.

Tim Andrews is a renaissance person and problem solver and an expert in emerging technology and innovation.

A technology leader in Booz Allen Hamilton's Civilian Services business, Tim also has broad expertise beyond technology, including in strategy, cognitive psychology, health care, and life sciences. He has significant experience in large-scale system design and development and advances client missions through pragmatic use of leading-edge technology. He has been a prolific writer and public speaker throughout his career.

Tim has been an independent adviser and in leadership positions in firms ranging from startups to large corporations. Prior to Booz Allen, he helped create New York's innovative health information network as Chief Architect and worked with large corporations to develop and implement their technology strategies. In the late '90s, Tim was Chief Technology Officer for Viant, one of the first and most successful publicly traded internet consulting companies, where he led the innovation group and worked with clients to help them understand and capitalize on the internet. Tim was a partner at Diamond Management & Technology Consultants (now part of PwC), where he led the development of the digital strategy practice in the mid-'90s. Early in his career, in one of his most exciting experiences, he worked on the software for the original Macintosh computer and was a founder and Chief Technology Officer of one of the first unstructured database startups.

Tim holds an A.B in engineering from Dartmouth College and an MS in computer science and electrical engineering from Worcester Polytechnic Institute.



BUY THE BOOK!

JOIN THE
CONVERSATION

Inventing the Future

ADVANCE PRAISE FOR

A Brief History *of a* Perfect Future

"*A Brief History of a Perfect Future* presents us with a rare gift in this era of pervasive negativity, anonymous grousing, and divisiveness. It offers a positive and optimistic view of our future, grounded in facts and the lessons of history. It is both inspirational and aspirational on how we can make this vision a reality. Highly recommended! Reading it should put a spring in your step and a smile on your face!"

—**BRAN FERREN, Chief Creative Officer, Applied Minds, and former President of Research and Development, The Walt Disney Company**

"This book reminds us that the future is our choice. It inspires the bold thinking and creativity required to change our world for the better. This is a must read for public and private sector leaders with the awesome opportunity to shape the trajectory of progress."

—**KRISTINE MARTIN ANDERSON, EVP and leader, Civil Services, Booz Allen Hamilton**

"This book takes a future-back approach in which commonly perceived constraints on the future state are released, permitting the starting point of that perfect future. I really liked the illuminating stories, how this feels like a logical extension of the authors' previous books, and the great writing paired with the imaginative Law of Zero concept. A compelling, interesting read that is also quite a bit of fun!"

—**JAMES MADARA, MD, CEO, American Medical Association**

"As one who has seen first-hand how even one tool can change the world, it's exciting to read the future histories of the seven drivers laid out in this insightful book. We can combine them for a wonderful future—if we take the right steps!"

—**DAN BRICKLIN, inventor of the spreadsheet**

"We are the designers of our future. The authors help us be idealistic, yet pragmatic, in reimagining our future. Most importantly, they show us a smart path forward; the time has come to "think big, start small, and learn fast." Thanks to the unprecedented speed of innovation, "near-miracles" are possible. We can get to our Future Perfect, *if* we start now to make the right choices."

—**LINDA A. HILL, Wallace Brett Donham Professor of Business Administration, Harvard Business School, and author of *Collective Genius: The Art and Practice of Leading Innovation***

"… a tremendously fun journey through a future that's both plausible and necessary if we want to create a thriving world. This book provides a much-needed jolt of optimism about humanity's ability to overcome our greatest challenges."

—**ANDREW WINSTON, sustainability strategist, author of *Green to Gold* and *Net Positive***

www.perfectfuturebook.com

ISBN 978-0-9892420-5-9
US$21.99
52199
9 780989 242059