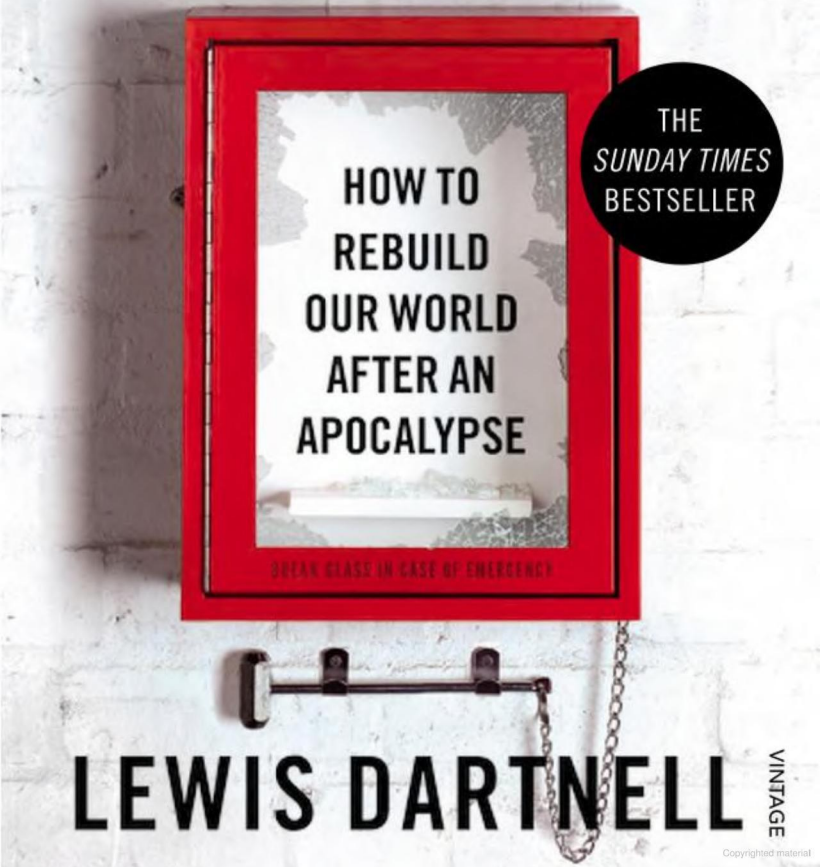
'A glorious compendium of the knowledge we have lost...
The most inspiring book I've read in a long time'
INDEPENDENT

THE KNOWLEDGE



THE *SUNDAY TIMES* BESTSELLER

LEWIS DARTNELL

VINTAGE

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The Knowledge

How To Rebuild Our World After An Apocalypse

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'These fragments I have shored against my ruins'

The Waste Land, T. S. Eliot

Introduction

The world as we know it has ended.

A particularly virulent strain of avian flu finally breached the species barrier and hopped successfully to human hosts, or perhaps was deliberately released in an act of bioterrorism. The contagion spread devastatingly quickly in the modern age of high-density cities and intercontinental air travel, and killed a large proportion of the global population before any effective immunisation or even quarantine orders could be implemented.

Or maybe tensions between India and Pakistan reached breaking point and a border dispute escalated beyond all rational limits, culminating in the use of nuclear weapons. The warheads' distinctive electromagnetic pulses were detected by defence surveillance in China, and triggered a round of pre-emptive launches against the United States, which in turn spurred retaliatory strikes by America and its allies in Europe and Israel. Major cities worldwide were reduced to jagged plains of radioactive glass. The enormous volumes of dust and ash injected into the atmosphere reduced the amount of sunlight reaching the ground, causing a decades-long nuclear winter, the collapse of agriculture, and global famine.

Or perhaps the event was entirely beyond human control. A rocky asteroid, only about a kilometre across, slammed into the Earth and fatally changed atmospheric conditions. People

within a few hundred kilometres of ground zero were dispatched in an instant by the blast wave of intense heat and pressure, and from that point on most of the rest of humanity was living on borrowed time. It didn't really matter which nation it struck: the rock and dust hurled up high into the atmosphere – as well as the smoke produced by widespread fires ignited by the heat blast – dispersed on the winds to smother the entire planet. As in a nuclear winter, global temperatures dropped enough to cause worldwide crop failures and massive famine.

This is the stuff of so many novels and films featuring post-apocalyptic worlds. The immediate aftermath is often – as in *Mad Max* or Cormac McCarthy's novel *The Road* – portrayed as barren and violent. Roving bands of scavengers hoard the remaining food, and prey ruthlessly on those less well organised or armed. I suspect that, at least for a period after the initial shock of collapse, this might not be too far from the truth. I'm an optimist, though: I think morality and rationality would ultimately prevail, and settlement and rebuilding begin.

The world as we know it has ended. The crucial question is: what now?

Once the survivors have come to terms with their predicament – the collapse of the entire infrastructure that previously supported their lives – what can they do to rise from the ashes and ensure they thrive in the long term? What knowledge would they need to recover as rapidly as possible?

This is a survivors' guidebook. Not one concerned simply with keeping people alive in the weeks after the apocalypse – plenty of handbooks have been written on survival skills – but one that teaches how to orchestrate the rebuilding of a technologically advanced civilisation. If you suddenly found yourself without a working example, could you explain how to build an internal combustion engine, or a clock, or a microscope? Or, even more basic, how to successfully cultivate crops and make clothes? But the apocalyptic scenarios I'm presenting here are also the starting point for a thought experiment: they are a vehicle for examining the fundamentals of science and

technology which, as knowledge becomes ever more specialised, feel very remote to most of us.

People living in developed nations have become disconnected from the processes of the civilisation that supports them. Individually, we are astoundingly ignorant of even the basics of the production of food, shelter, clothes, medicine, materials or vital substances. Our survival skills have atrophied to the point that much of humanity would be incapable of sustaining itself if the life-support system of modern civilisation failed, if food no longer magically appeared on shop shelves, or clothes on hangers. Of course, there was a time when everyone was a survivalist, with a far more intimate connection to the land and methods of production, and to survive in a post-apocalyptic world you'd need to turn back the clock and relearn these core skills.*

What's more, each piece of modern technology we take for granted requires an enormous support network of other technologies. There's much more to making an iPhone than knowing the design and materials of each of its components. The device sits as the capstone on the very tip of a vast pyramid of enabling technologies: the mining and refining of the rare element indium for the touchscreen, high-precision photolithographic manufacturing of microscopic circuitry in the computer-processing chips, and the incredibly miniaturised components in the microphone, not to mention the network of radio masts and infrastructure necessary to maintain telecommunications and the functioning of the phone. The first generation born after the Fall would find the internal mechanisms of a modern phone absolutely inscrutable, the pathways of its microchip circuits invisibly small to the human eye and their purpose utterly

* Similar, small-scale scenarios have occurred in recent history: with the fall of the Soviet Union in 1991, the small republic of Moldova experienced a crippling crash in its economy, forcing people to become self-sufficient and to readopt museum-exhibit technology like spinning wheels, hand looms and butter churns.

mysterious. The sci-fi author Arthur C. Clarke said in 1961 that any sufficiently advanced technology is indistinguishable from magic. In the aftermath, the rub is that this miraculous technology would belong not to some star-faring alien being, but to a generation in our own past.

Even quotidian artefacts of our civilisation that aren't particularly high-tech still require a diversity of raw materials that must be mined or otherwise gathered, processed in specialised plants, and the distinct components assembled in a manufacturing facility. And all of this in turn relies on electrical power stations and transport over great distances. This point is made very eloquently in Leonard Read's 1958 essay written from the perspective of one of our most basic tools, 'I, Pencil'. The astounding conclusion is that because the sourcing of raw materials and production methods are so dispersed, there is not a single person on the face of the Earth who has the ability and resources to make even this simplest of implements.

A potent demonstration of the gulf that now separates our individual capabilities and the production of even simple gizmos in our everyday life was offered by Thomas Thwaites when in 2008 he attempted to make a toaster from scratch while studying for his MA at the Royal College of Art. He reverse-engineered a cheap toaster down to its barest essentials – iron frame, mica-mineral insulating sheets, nickel heating-filaments, copper wires and plug, and plastic casing – and then sourced all the raw materials himself, digging them out of the ground in quarries and mines. He also looked up simpler, historical metallurgical techniques, referring to a sixteenth-century text to build a rudimentary iron-smelting furnace, using a metal dustbin, barbecue coals, and a leaf blower for bellows. The finished model is satisfyingly primitive, but also grotesquely beautiful in its own right and neatly underscores the core of our problem.

Of course, even in one of the extreme doomsday scenarios, groups of survivors would not need to become self-sufficient immediately. If the great majority of the population succumbed

to an aggressive virus, there would still be vast resources left behind. The supermarkets would remain stocked with plentiful food, and you could pick up a fine new set of designer clothes from the deserted department stores or liberate the sports car you've always dreamed about from the showroom. Find an abandoned mansion, and with a little foraging it wouldn't be too hard to salvage some mobile diesel generators to keep the lighting, heating and appliances running. Underground lakes of fuel remain beneath petrol stations, sufficient to keep your new home and car functioning for a significant period. In fact, small groups of survivors could probably live pretty comfortably in the immediate aftermath of the apocalypse. For a while, civilisation could coast on its own momentum. The survivors would find themselves surrounded by a wealth of resources there for the taking: a bountiful Garden of Eden.

But the Garden is rotting.

Food, clothes, medicines, machinery and other technology inexorably decompose, decay, deteriorate and degrade over time. The survivors have nothing more than a grace period. With the collapse of civilisation and the sudden arrest of key processes – gathering raw materials, refining and manufacturing, transportation and distribution – the hourglass is inverted and the sand steadily draining away. The remnants provide nothing more than a safety buffer to ease the transition to the moment when harvesting and manufacturing must begin anew.

A REBOOT MANUAL

The most profound problem facing survivors is that human knowledge is collective, distributed across the population. No one individual knows enough to keep the vital processes of society going. Even if a skilled technician from a steel foundry survived, he would only know the details of *his* job, not the subsets of knowledge possessed by other workers at the foundry

that are vital for keeping it running – let alone how to mine iron ore or provide electricity to keep the plant operating. The most visible technology we use daily is just the tip of a vast iceberg – not only in the sense that it's based on a great manufacturing and organisational network that supports production, but also because it represents the heritage of a long history of advances and developments. The iceberg extends unseen through both space and time.

So where would survivors turn? A great deal of information will certainly remain in the books gathering dust on the shelves of the now-deserted libraries, bookshops and homes. The problem with this knowledge, however, is that it isn't presented in a way appropriate for helping a fledgling society – or an individual without specialist training. What do you think you'd understand if you pulled a medical textbook off the shelf and flipped through the pages of terminology and drug names? University medical textbooks presuppose a huge amount of prior knowledge, and are designed to work alongside teaching and practical demonstrations by established experts. Even if there were doctors among the first generation of survivors, they'd be severely limited in what they could accomplish without test results or the cornucopia of modern drugs they were trained to use – drugs which would be degrading on pharmacy shelves or in defunct hospital storage refrigerators.

Much of this academic literature would itself be lost, perhaps to fires ripping unchecked through empty cities. Even worse, much of the wealth of new knowledge generated each year, including that which I and other scientists produce and consume in our own research, is not recorded on any durable medium at all. The cutting edge of human understanding exists primarily as ephemeral bits of data: as academic 'papers' stored on the website servers of specialist journals.

And the books aimed at general readers wouldn't be much more help. Can you imagine a group of survivors who only had access to the selection of books stocked in an average bookshop? How far would a civilisation get, trying to rebuild

itself from the wisdom contained in the pages of self-help guides on how to succeed in business management, think yourself thin, or read the body language of the opposite sex? The most absurd nightmare would be a post-apocalyptic society discovering a few yellowed and crumbly books and, thinking them the scientific wisdom of the ancients, trying to apply homeopathy to curb a plague or astrology to forecast harvests. Even the books in the science section would offer little help. The latest pop-sci page-turner may be engagingly written, make clever metaphorical use of everyday observations, and leave the reader with a deeper understanding of some new research, but it probably won't yield much pragmatic knowledge. In short, the vast majority of our collective wisdom would not be accessible – at least in a usable form – to the survivors of a cataclysm. So how best to help the survivors? What key information would a guidebook need to deliver, and how might it be structured?

I'm not the first person to wrestle with this question. James Lovelock is a scientist with a formidable track record in striking at the heart of an issue long before his peers. He is most famous for his Gaia hypothesis, which posits that the entire planet – a complex assemblage of rocky crust and oceans and swirling atmosphere, along with the thin smear of life that has established itself across the surface – can be understood as a single entity that acts to dampen down instabilities and self-regulate its environment over billions of years. Lovelock is deeply concerned that one element of this system, *Homo sapiens*, now has the capacity to disrupt these natural checks and balances with devastating effect.

Lovelock draws on a biological analogy to explain how we might safeguard our heritage: 'Organisms that face desiccation often encapsulate their genes in spores so that the information for their renewal is carried through the drought.' The human equivalent envisaged by Lovelock is a book for all seasons, 'a primer on science, clearly written and unambiguous in its meaning – a primer for anyone interested in the state of the Earth and how to survive and live well on it'. What he proposes

is a truly massive undertaking: recording the complete assemblage of human knowledge in a huge textbook – a document that you could, at least in principle, read from cover to cover and then walk away knowing the essentials of everything that is now known.

In fact, the idea of a 'total book' has a much longer history. In the past, encyclopaedia compilers appreciated far more acutely than we do today the fragility of even great civilisations, and the exquisite value of the scientific knowledge and practical skills held in the minds of the population that evaporates once the society collapses. Denis Diderot explicitly regarded the role of his *Encyclopédie*, the first volume of which was published in 1751, to serve as a safe repository of human knowledge, to preserve it for posterity in case of a cataclysm that snuffs our civilisation as the ancient cultures of the Egyptians, Greeks and Romans had all been lost, leaving behind only random surviving fragments of their writing. In this way, the encyclopaedia becomes a time capsule of accumulated knowledge, all arranged logically and cross-referenced, protected against the erosion of time in case of widespread catastrophe.

Since the Enlightenment our understanding of the world has increased exponentially and the task of compiling a complete compendium of human knowledge would be orders of magnitude harder today. The creation of such a 'total book' would represent a modern-era Pyramid-building project, requiring the full-time exertion of tens of thousands of people over many years. The purpose of this toil would be to ensure not the safe passage of a pharaoh to eternal bliss in the afterworld but the immortality of our civilisation itself.

Such an all-consuming undertaking is not inconceivable if the will is there. My parents' generation worked hard to put the first man on the moon: at its peak the Apollo program employed up to 400,000 people and consumed 4 per cent of the total American federal budget. Indeed, you might think that the perfect compendium of current human knowledge has

already been created by the phenomenal combined effort of the committed volunteers behind Wikipedia. Clay Shirky, an expert on the sociology and economics of the internet, has estimated that Wikipedia currently represents around 100 million man-hours of devoted effort in writing and editing. But even if you could print Wikipedia in its entirety, its hyperlinks replaced by cross-referenced page numbers, you'd still be a far cry from a manual enabling a community to rebuild civilisation from scratch. It was never intended for anything like this purpose and lacks practical details or the organisation needed to guide progression from rudimentary science and technology to more advanced applications. Moreover, a hard copy would be unfeasibly large – and how could you ensure post-apocalyptic survivors would be able to get hold of a copy? In fact, I believe you can help society recover much better by taking a slightly more elegant approach.

The solution can be found in a remark made by physicist Richard Feynman. In hypothesising about the potential destruction of all scientific knowledge and what might be done about it, he allowed himself a single statement to be transmitted securely to whichever intelligent creatures emerged after the cataclysm. What sentence holds the most information in the fewest words? 'I believe,' says Feynman, 'it is the atomic hypothesis: that all things are made of atoms – little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.'

The more you consider the implications and testable hypotheses emerging from this simple statement, the more it unfurls to release further revelations about the nature of the world. The attraction of particles explains the surface tension of water and the mutual repulsion of atoms in close proximity explains why I don't fall straight through the café chair I'm sitting on. The diversity of atoms, and the compounds produced by their combinations, is the key principle of chemistry. This single, carefully crafted sentence encapsulates a huge density

of information, which unravels and expands as you investigate it.

But what if your word count wasn't quite so restricted? If allowed the luxury of being more expansive, while retaining the guiding principle of providing key, condensed knowledge to accelerate rediscovery rather than attempting to write a complete encyclopaedia of modern understanding, is it feasible to write a single volume that would constitute a survivor's quick-start guide to rebooting technological society?

I think that Feynman's single sentence can be improved upon in a fundamentally important way. Possessing *pure* knowledge alone with no means to exploit it is not enough. To help a fledgling society pull itself up by its own bootstraps you also have to suggest how to *utilise* that knowledge, to show its practical applications. For the survivors of a recent apocalypse, the immediate practical applications are essential. Understanding the basic theory of metallurgy is one thing, but using the principles to scavenge and reprocess metals from the dead cities, for instance, is another. Exploitation of knowledge and scientific principles is the essence of technology and, as we'll see in this book, the practices of scientific research and technological development are inextricably intertwined.

Inspired by Feynman, I'd argue that the best way to help survivors of the Fall is not to create a comprehensive record of all knowledge, but to provide a guide on the basics, adapted to their likely circumstances, as well as a blueprint of the techniques necessary to rediscover crucial understanding for themselves – the powerful knowledge-generation machinery that is the scientific method. The key to preserving civilisation is to provide a condensed seed that will readily unpack to yield the entire expansive tree of knowledge, rather than attempting to document the colossal tree itself. Which fragments, to paraphrase T. S. Eliot, are best shored against our ruins?

The value of such a book is potentially enormous. Imagine what might have happened in our own history if the classical civilisations had left seeds of their accumulated knowledge.

One of the major catalysts for the Renaissance in the fifteenth and sixteenth centuries was the trickle of ancient learning back into Western Europe. Much of this knowledge, lost with the fall of the Roman Empire, was preserved and propagated by Arabic scholars who carefully translated and copied texts, other manuscripts were rediscovered by European scholars. But what if these treatises on philosophy, geometry and practical mechanisms had been preserved in a distributed network of time capsules? And similarly, with the right book available, could a post-apocalyptic Dark Ages be averted?*

ACCELERATED DEVELOPMENT

During a reboot, there's no reason to retrace the same route to scientific and technological sophistication. Our original path through history has been long and tortuous; we've stumbled along in a largely haphazard manner, chasing red herrings and overlooking crucial developments for long periods. But with 20/20 hindsight, knowing what we know now, could we give directions for a direct route to crucial advances, taking short cuts like an experienced navigator? How might we chart the optimal route through the vastly interlinked network of scientific principles and enabling technologies to accelerate progress as much as possible?

Key breakthroughs are often serendipitous – they were stumbled upon by chance in our history. Alexander Fleming's discovery of the antibiotic properties of the *Penicillium* mould

* If you ignore the material that will be left behind by the collapse of our society, this thought experiment on aiding the recovery of survivors could also provide the manual you'd need to develop a technological civilisation from scratch after accidentally falling through a time warp into the Palaeolithic era ten thousand years in the past, or crash-landing a spaceship on an uninhabited but clement Earth-like planet. This is the ultimate Robinson Crusoe or Swiss Family Robinson shipwreck fantasy – not washing up on a small deserted island, but starting again on an empty world.

in 1928 was a chance occurrence. And indeed, the observation that first hinted at the deep coupling between electricity and magnetism – the twitching of compass needles left next to a wire carrying current – was fortuitous, as was the discovery of X-rays. Many of these key discoveries could just as easily have happened earlier, some of them substantially so. Once new natural phenomena have been discovered progress is driven by systematic and methodical investigation to understand their workings and quantify their effects, but the initial uncovering can be targeted with a few choice hints to the recovering civilisation on where to look and which investigations to prioritise.

Likewise, many inventions seem obvious in retrospect, but sometimes the time of emergence of a key advance or invention doesn't appear to have followed any particular scientific discovery or enabling technology. For the prospects of a rebooting civilisation, these cases are encouraging because it means the quick-start guide need only briefly describe a few central design features for the survivors to figure out exactly how to recreate some key technologies. The wheelbarrow, for instance, could have been made centuries before it actually was – if only someone had thought of it. This may seem a trivial example, combining the operating principles of the wheel and the lever, but it represents an enormous labour-saver and didn't appear in Europe until millennia after the wheel (the first depiction of one appears in an English manuscript written about 1250 AD).

Other innovations have such wide-ranging effects that you would want to beeline directly towards them to support many other elements of the post-apocalyptic recovery. The movable-type printing press is one such gateway technology that accelerated development and had incomparable social ramifications in our history. With a little guidance, mass-produced books could reappear early in the rebuilding of a new civilisation, as we'll see later.

When developing new technologies, some steps in the progression could be skipped altogether. The quick-start guide

could aid a recovering society by showing how to leapfrog over intermediate stages from our history to more advanced, yet still achievable, systems. There are a number of encouraging cases of this kind of technological leapfrogging in the developing nations in Africa and Asia today. For example, many remote communities unconnected to power grids are receiving solar power infrastructure, hopping over centuries of the Western progression dependent on fossil fuels. Villagers living in mud huts in many rural parts of Africa are leapfrogging straight to mobile phone communications, bypassing intermediate technologies like semaphore towers, telegraphs or landline telephones.

Perhaps the most impressive feat of leapfrogging in history was achieved by Japan in the nineteenth century. During the Tokugawa shogunate, Japan isolated itself for two centuries from the rest of the world, forbidding its citizens to leave, or foreigners to enter, and permitting only minimal trade with a select few nations. Contact was re-established in the most persuasive manner in 1853 when the US Navy arrived in the Bay of Edo (Tokyo) with powerfully weaponised steam-powered warships, far superior to anything possessed by the technologically stagnant Japanese civilisation. The shock of realisation of this technological disparity triggered the Meiji restoration. Japan's previously isolated, technologically backward feudal society was transformed by a series of political, economic and legal reforms, and foreign experts in science, engineering and education instructed the nation how to build telegraph and railroad networks, textile mills and factories. Japan industrialised in a matter of decades, and by the time of the Second World War was able to take on the might of the US Navy that had forced this process in the first place.

Could a preserved cache of appropriate knowledge allow a post-apocalyptic society to achieve a similarly rapid developmental trajectory?

Unfortunately, there are limits to how far ahead you can push a civilisation by skipping intermediate stages. Even if the

post-apocalyptic scientists fully understand the basis of an application and produce a design that would work in principle, it may still be impossible to build a working prototype. I call this the Da Vinci effect. The great Renaissance inventor generated endless designs for mechanisms and contraptions, such as his fantastic flying machines, but few of them were ever realised. The problem was largely that Da Vinci was too far ahead of his time. Correct scientific understanding and ingenious designs aren't sufficient: you also need a matching level of sophistication in construction materials with the necessary properties and available power sources.

So the trick for a quick-start guide must be to provide appropriate technology for the post-apocalyptic world, in the same way that aid agencies today supply suitable intermediate technologies to communities in the developing world. These are solutions that offer a significant improvement to the status quo – an advance from the existing, rudimentary technology – but which can still be repaired and maintained by local workmen with the practical skills, tools and materials available. The aim for an accelerated reboot of civilisation is to jump directly to a level that saves centuries of incremental development but can still be reached using rudimentary materials and techniques – the *sweet-spot* intermediate technology.

It is these features of our own history – serendipitous discoveries, inventions that were not waiting for any prerequisite knowledge, gateway technologies that stimulated progress in many areas, and opportunities to leapfrog intermediate stages – which give us optimism that a well-designed quick-start manual for civilisation could give directions towards the most fertile investigations and the crucial principles behind key technologies: guiding an optimal route through the web of science and technology and greatly accelerating rebuilding. Imagine science when you're not fumbling around in the dark: your ancestors have equipped you with a flashlight and a rough map of the landscape.

If a rebooting civilisation is not constrained to following our

own idiosyncratic path of progress it will experience a completely different sequence of advances. Indeed, rebooting along the trajectory that our current civilisation followed might now be very difficult. The Industrial Revolution was largely powered by fossil energy. Most of these easily accessible fossil energy sources – deposits of coal, oil and natural gas – have now been mined towards depletion. Without access to such readily available energy, how could a civilisation following ours haul itself through a second industrial revolution? The solution, as we'll see, will lie in early adoption of renewable energy sources and careful recycling of assets – sustainable development will probably be forced on the next civilisation out of sheer necessity: a Green reboot.

In the process, unfamiliar combinations of technologies will emerge over time. We will take a look at examples of where a recovering society is likely to take a different trajectory in their development – the path not travelled – as well as utilising technological solutions that for us have fallen by the wayside. To us, Civilisation 2.0 might look like a mishmash of technologies from different eras, not unlike the genre of fiction known as steampunk. Steampunk narratives are set in an alternative history that has followed a different pattern of development and is often characterised by a fusion of Victorian technology with other applications. A post-apocalyptic reboot with very different rates of progress in separate fields of science and technology is likely to lead to such an anachronistic patchwork.

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A reboot manual would work best on two levels. First, you need a certain amount of practical knowledge handed to you on a plate, so as to recover a base level of capability and a comfortable lifestyle as quickly as possible, and to halt further degeneration. But you also need to nurture the recovery of

scientific investigation and provide the most worthwhile kernels of knowledge to begin exploring.*

We'll start with the basics and see how you can provide the fundamental elements of a comfortable life for yourself: sufficient food and clean water, clothes and building materials, energy and essential medicines. There will be a number of immediate concerns for survivors: cultivatable crops must be gathered from farmland and seed caches before they die and are lost; diesel can be rendered from biofuel crops to keep engines running until the machinery fails, and parts scavenged to re-establish a local power grid. We'll look at how best to cannibalise components and scavenge materials from the detritus of the dead civilisation: the post-apocalyptic world will demand ingenuity in repurposing, tinkering and jury-rigging.

Once the essentials are in place, I'll explain how to re-instate agriculture, safely preserve a stockpile of food, and how plant and animal fibres can be turned into clothes. Materials such as paper, ceramic pottery, brick, glass and wrought iron are today so commonplace that they are considered prosaic and boring – but how could you make them if you needed to? Trees yield an enormous amount of remarkably useful stuff: from timber material for construction to charcoal for purifying drinking water, as well as providing a fiercely burning solid fuel. A whole range of crucial

* Whilst the most discernible features of a society may be its grand monuments, or art, music or other cultural output, the basics supporting civilisation are fundamentals such as agricultural productivity, sewage treatment and chemical synthesis. This book will focus on the critical science and technology, as they are universal: a particular physical law is true no matter where (or when) you are, and a society even thousands of years in the future will have the same basic needs that can be alleviated by technology – food, clothes, power, transport and so on. Art, literature and music are an important part of our cultural heritage, but the recovery of civilisation wouldn't be held back half a millennium without them, and the post-apocalyptic survivors will develop their own expressions that have relevance for them.

1

The End of the World as we Know it

'The most glorious moment for a work of this sort would be that which might come immediately in the wake of some catastrophe so great as to suspend the progress of science, interrupt the labors of craftsmen, and plunge a portion of our hemisphere into darkness once again.'

Denis Diderot, *Encyclopédie* (1751–1772)

The seemingly obligatory scene in any disaster movie is a panning shot across a broad highway gridlocked with tightly packed vehicles attempting to flee the city. Instances of extreme road rage flare as drivers grow increasingly desperate, before abandoning their cars amongst the others already littering the hard shoulders and lanes and joining the droves of people pushing onwards on foot. Even without an immediate hazard, any event that disrupts distribution networks or the electrical grid will starve the cities of their voracious appetite for resources and force their inhabitants out in a hungry exodus: mass migrations of urbanite refugees swarming into the surrounding countryside to scavenge for food.

TEARING UP THE SOCIAL CONTRACT

I don't want to get stuck in the philosophical quagmire of debating whether mankind is intrinsically evil or not, and

whether a controlling authority is a necessary construct to impose a set of laws and maintain order through the threat of punishment. But it is clear that with the evaporation of centralised governance and a civil police force, those with ill intentions will seize the opportunity to subjugate or exploit the more peaceful or vulnerable. And once the situation seems sufficiently dire, even previously law-abiding citizens will resort to whatever action is necessary to provide for and protect their own families. To ensure your own survival you may have to forage and scavenge for what you need: a polite euphemism for looting.

Part of the glue that binds societies together is the expectation that the pursuit of short-term gains through deception or violence is far outweighed by the long-term consequences. You'll be caught and socially stigmatised as an untrustworthy partner or punished by the state: cheats don't prosper. This tacit agreement between individuals in a society to co-operate and behave for the collective good, sacrificing a certain amount of personal freedom in exchange for benefits such as the mutual protection offered by the state, is known as the social contract. It is the very foundation of all collective endeavour, production and economic activity of a civilisation, but the structure begins to strain and social cohesion loosens once individuals perceive greater personal gains in cheating, or suspect that others will cheat them.

During a severe crisis the social contract can snap, precipitating the total disintegration of law and order. We need look no further than the most technologically advanced nation on the planet to see the effects of a localised fracture in the social contract. New Orleans was physically devastated by the rampage of Hurricane Katrina, but it was the desperate realisation by the city's inhabitants that local governance had evaporated and no help would be arriving any time soon that saw the rapid degeneration of normal social order and the outbreak of anarchy.

So after a cataclysmic event, following the evaporation of governance and law enforcement, we might expect organised gangs to emerge to fill the power vacuum, laying claim to their

own personal fiefdoms. Those who seize control of the remaining resources (food, fuel, and so on) will administer the only items that have any inherent value in the new world order. Cash and credit cards will be meaningless. Those appropriating the caches of preserved food as their own 'property' will become very wealthy and powerful – the new kings – controlling the allocation of food to buy loyalty and services just as ancient Mesopotamian emperors did. In this environment, people with special skills, such as doctors and nurses, might do well to keep this to themselves, as they might be forced to serve the gangs as highly specialised slaves.

Lethal force may be applied swiftly to deter looters and raids from rival gangs, and as resources become depleted the competition will only get fiercer. A common mantra of people who actively prepare for the apocalypse (called preppers) is that: 'it is better to have a gun and not need it, than to need a gun and not have it'.

One pattern likely to recur during the first weeks and months is that small communities of people will gather together in a defensible location for mutual support and protection of their own stash of consumables, looking for safety in numbers. These small dominions will need to patrol and protect their own borders in the way that nations do today. Ironically, the safest place for a group to barricade themselves in and hunker down during the turbulence would be one of the fortresses dotted across the country, but now turned inside-out in its purpose. Prisons are largely self-contained compounds with high walls, sturdy gates, barbed wire, and watch towers, originally intended to prevent the inhabitants from escaping but equally effective as a defensive refuge for keeping others out.

The outbreak of widespread crime and violence is probably an inevitable effect of any catastrophic event. However, this hellish descent into a *Lord of the Flies* world is not something I will discuss further here. This book is about how to fast-track the recovery of technological civilisation once people are able to settle down again.

THE BEST WAY FOR THE WORLD TO END

Before we get to the 'best', let's start with the worst. From the point of view of rebuilding civilisation, the worst kind of doomsday event would be all-out nuclear war. Even if you escape vaporisation in the targeted cities, much of the material of the modern world will have been obliterated and the dust-darkened skies and ground poisoned by fallout would hamper the recovery of agriculture. Just as bad, even though it is not directly lethal, would be an enormous coronal mass ejection from the sun. A particularly violent solar burp would slam into the magnetic field around our planet, set it ringing like a bell, and induce enormous currents in the electricity distribution wires, destroying transformers and knocking out electrical grids across the planet. The global power blackout would disrupt the pumping of water and gas supplies and the refining of fuel, as well as the production of replacement transformers. With such devastation of the core infrastructure of modern civilisation without any immediate loss of life, the collapse of social order would soon follow and roving crowds would rapidly consume the remaining supplies, precipitating mass depopulation. At the end, survivors would still encounter a world without people, but one that has now been stripped bare of any resources that would have offered them a grace period for recovery.

While the dramatic scenario favoured by many post-apocalyptic movies and novels may be the collapse of industrial civilisation and social order, forcing survivors to engage in an increasingly frantic struggle for dwindling resources, the scenario I want to focus on is the inverse: a sudden and extreme depopulation that leaves the material infrastructure of our technological civilisation untouched. The majority of humanity has been erased, but all of the stuff is still around. This scenario presents the most interesting starting point for the thought experiment on how to accelerate the rebuilding of civilisation from scratch. It grants the survivors a grace period to find their feet,

preventing a degenerative slide too far, before they need to relearn the essential functions of a self-supporting society.

To come to this scenario, the best way for the world to end would be at the hands of a fast-spreading pandemic. The perfect viral storm is a contagion that combines aggressive virulence, a long incubation period and near 100 per cent mortality. This way, the agent of the apocalypse is extremely infectious between individuals, takes a little while for its sickness to kick in (so that it maximises the pool of subsequent hosts that are infected) but results in certain death in the end. We have become a truly urban species – since 2008 the majority of the global population have lived in cities rather than rural areas – and this crammed density of people, along with fervent intercontinental travel, provides the perfect conditions for the rapid transmission of contagion. If a plague like the Black Death of the 1340s, which wiped out a third of the European population (and probably a similar proportion across Asia), were to strike today our technological civilisation would be much less resilient.*

What, then, is the minimum number of survivors of a global catastrophe needed to have a feasible chance not just of repopulating the world but of being able to accelerate the rebuilding of civilisation? To put it another way: what is the critical mass to enable a rapid reboot?

The two extremes of the spectrum of surviving populations I will call the *Mad Max* and *I Am Legend* scenarios. If there is an implosion of the technological life-support system of modern society but no immediate depopulation (such as triggered by a coronal mass ejection), most of the population survives to rapidly consume any remaining resources in fierce competition. This wastes the grace period, and society promptly

* However, some of the longer-term ramifications of the Black Death were beneficial to society: a cultural silver lining to the cloud that was the Great Dying. With the ensuing labour shortage, serfs who survived the mass depopulation were able to slip their bond to the Lord of the Manor, helping break the oppressive feudal system and ushering in a much more egalitarian social structure and market-orientated economy.

Buildings crumble and nature reclaims our urban spaces, including our stores of knowledge like this New Jersey library.

punishing freeze–thaw cycle that steadily wears down entire mountain ranges. This weathering creates more and more niches for small opportunistic weeds, and then shrubs, to become established and further break up the surface. Other plants are more aggressive, their penetrating roots pushing right through the bricks and mortar to find purchase and tap into sources of moisture. Vines will snake their way up traffic lights and street signs, treating them like metallic tree trunks, and lush coatings of creepers will grow up the cliff-like faces of buildings and spread down from the rooftops.

Over a number of years, accumulating leaf litter and other vegetative matter from this pioneering burst of growth decays to an organic humus and mixes with the windblown dust and grit of deteriorating concrete and bricks to create a genuine urban soil. Papers and other detritus billowing out of broken office windows will collect in the streets below and add to this composting layer. A thickening carpet of dirt will smother the

roads, pavements, parking lots and open spaces of towns and cities, allowing a succession of larger trees to take root. Away from the tarmacked streets and paved squares, the cities' grassy parks and the surrounding countryside will rapidly return to woodland. In just a decade or two, elder thickets and birch trees will have become firmly established, maturing to dense woods of spruce, larch and chestnut by the end of the first century after the apocalypse.

And while nature is busy reclaiming the environment, our buildings will crumble and decay among the growing forests. As vegetation returns and fills the streets with wood and drifts of windblown leaves, mingling with the rubbish cascading from broken windows, piles of perfect kindling will collect in the streets and the chance of raging urban forest fires increases. Tinder accumulated against the side of a building and ignited by a summer lightning storm, or perhaps sunlight focused through broken glass, is all that's needed to unleash devastating wildfires that spread along the streets and burn up the inside of high-rises.

A modern city wouldn't be razed to the ground like London in 1666 or Chicago in 1871, the fire ripping rapidly from one wooden building to the next and leaping across the narrow streets, but blazes spreading unopposed by firefighters would still be devastating. Gas lingering in underground pipes and throughout buildings would explode, with fuel left in tanks of vehicles abandoned in the streets adding to the intensity of the inferno. Dotted throughout populated areas are bombs waiting to go off when a blaze sweeps through: petrol stations and chemical depots. Perhaps one of the most poignant sights for the post-apocalyptic survivors would be the burning of the old cities, thick columns of choking black smoke towering above the landscape and turning the sky blood red at night. After a passing blaze, the brick, concrete and steel matrix of contemporary buildings would be all that is left – charred skeletons once their combustible internal viscera have been gutted.

Fire will wreak devastation across great areas of the deserted cities, but it is water that will eventually bring certain destruction for all our carefully constructed buildings. The first winter after the apocalypse will see a spate of burst frozen water pipes, which will disgorge inside buildings during the following thaw. Rain will blow in through missing or broken windows, trickle down among dislodged roofing tiles and overflow from blocked gutters and drains. Peeled paint from window and door frames will allow moisture to soak in, rotting wood and corroding metal until the whole frame falls out of the wall. The wooden structures – floorboards, joists and roof supports – will also soak up moisture and rot, while the bolts, screws and nails holding the components together rust.

Concrete, bricks and the mortar smeared between them are subject to temperature swings, soaked with water trickling down from blocked gutters and pulverised by the relentless pulsing of freeze–thaw at high latitudes. In warmer climates, insects such as termites and woodworm will join forces with fungi to eat away at the wooden components of buildings. Before too long, wooden beams will decay and yield, causing floors to fall through and roofs to collapse, and eventually the walls themselves bow outwards then topple. The majority of our houses or apartment blocks will last, at most, a hundred years.

Our metal bridges will corrode and weaken as the paint peels off, allowing water to seep in. The death knell for many bridges, though, is likely to be windblown detritus collecting in the expansion gaps, breathing spaces designed to allow the materials to swell in the summer heat. Once clogged, the bridge will strain against itself, shearing off corroding bolts until the whole structure gives way. Within a century or two, many bridges will have collapsed into the water below, the lines of rubble and debris at the feet of the still-standing pillars forming a series of weirs in the river.

The steel-reinforced concrete of many modern buildings is a marvellous construction material, but although more resistant than wood, it is by no means impervious to decay. The ultimate

cause of its deterioration is ironically the source of its great mechanical strength. The steel reinforcing bars (rebars) are cocooned from the elements by the concrete surrounding them, but as mildly acidic rainwater soaks through, and humic acids released by rotting vegetation seep into the concrete foundations, the embedded steel begins to rust inside the structures. The final blow for this modern construction technique is the fact that steel expands as it rusts, rupturing the concrete from the inside, leaving even more surface exposed to moisture and so accelerating the endgame. These rebars are the weak point of modern construction – and unreinforced concrete will prove more durable in the long run: the dome of the Pantheon in Rome is still going strong after two thousand years.

The greatest threat to high-rises, though, is waterlogged foundations caused by unmaintained drainage, blocked sewers or recurrent floods, particularly among cities built along the banks of a river. Their supports will corrode and degrade, or subside into the ground to create a listing skyscraper far more ominous than the Leaning Tower of Pisa, before inevitably collapsing. The raining debris will further damage surrounding edifices, or the buildings may even topple over into neighbouring monoliths like giant dominoes, until only a few remain spiking above a skyline of trees. Few of our great high-rise buildings can be expected to be still standing after a few centuries.

Within just a generation or two the urban geography will have become unrecognisable. Opportunistic seedlings have become saplings have become full-blown trees. City streets and boulevards have been replaced by dense corridors of forest crammed into the artificial canyons between high-rise buildings, themselves now grossly dilapidated and trailing vegetation from gaping windows like vertical ecosystems. Nature has reclaimed the urban jungle. Over time, the jagged piles of rubble from collapsed buildings will themselves become softened by the accumulation of decomposing plant matter forming soil – hillocks of dirt sprouting trees, until even the tumbled remains of once-soaring skyscrapers are buried and hidden by verdant growth.

Away from the cities, fleets of ghost ships drift across the oceans, occasionally carried by the vagaries of wind and currents to ground themselves on a coastline, slicing open their bellies to bleed noxious slicks of fuel oil or releasing their load of containers on to the ocean currents like dandelion seeds in the wind. But perhaps the most spectacular shipwreck, if anyone happens to be in the right place at the right time to watch it, will be the return of one of humanity's most ambitious constructions.

The International Space Station is a giant 100-metre-wide edifice built over fourteen years in low Earth orbit: an impressive assemblage of pressurised modules, spindly struts, and dragonfly wings of solar panels. Although it soars 400 kilometres above our heads, the space station is not quite beyond the wispy upper reaches of the atmosphere, which exerts an imperceptibly slight but unrelenting drag on the sprawling structure. This saps the space station's orbital energy so that it spirals steadily towards the ground, and it needs to be repeatedly boosted back up with rocket thrusters. With the demise of the astronauts, or lack of fuel, the space station will relentlessly drop about 2 kilometres every month. Before long, it would be hauled down into a fiery plunge through the air, ending in a streak of light and fireball like an artificial shooting star.

THE POST-APOCALYPTIC CLIMATE

The gradual decay of our cities and towns is not the only transforming process that survivors will witness.

Since the Industrial Revolution and the exploitation of first coal and then natural gas and oil humanity has been fervently burrowing underground to dig up the buried chemical energy accumulated from times past. These fossil fuels, readily combustible dollops of carbon, are the decayed remains of ancient forests and marine organisms: chemical energy derived from the trapping of sunlight that shone on the Earth aeons ago. This carbon originally came from the atmosphere, but the

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The Grace Period

'Thus we never see the true state of our condition till it is illustrated to us by its contraries, nor know how to value what we enjoy, but by the want of it.'

Daniel Defoe, *Robinson Crusoe* (1719)

After a plane crash in a remote area, your main priorities for survival would be shelter, water and food. The same requirements are paramount after the crash of civilisation around you. While it's possible to survive for several weeks without food, and a few days without drinking water, if you're caught outside in an inclement climate you can die of exposure within a matter of hours. As the SAS survival expert John 'Lofty' Wiseman told me, 'If you're still on your feet after the big bang you are a survivor. But how long you continue to survive is down to your knowledge and what you do.' For our purposes we'll assume that, like more than 99 per cent of people, including myself, you're not a prepper and have not stockpiled food and water, fortified your home or made any other prior arrangements for the end of the world.

So during the crucial buffer period before you're forced to start producing things anew, what remnants could you scavenge to ensure your survival? What would you want to look out

for when beachcombing the detritus left by the receding technological tide?

SHELTER

In the situation we've imagined (loss of people, but no massive destruction of the stuff that surrounds us), you're not likely to lack shelter: there will be no shortage of abandoned buildings in the immediate aftermath. It would be well worth it, though, to embark immediately on a scavenging foray to a camping store to get yourself some new attire. The dress code for the end of the world is pragmatic: loose hard-wearing trousers, layers of warm tops, and a decent waterproof jacket will keep you comfortable while spending a lot more time in the open or in unheated buildings. Sturdy hiking boots may not look very glamorous, but in a post-apocalyptic world you really don't want to lose your footing and break an ankle. Over the first few years, the best place to forage for clothing that has not yet been destroyed by insects or the penetrating damp would be large shopping centres. It's a long way into the deep interior of a mall, and goods there are safe from the elements.

Warm clothes aside, it's fire that will ensure your survival. Fire has had a fundamental role in human history, protecting against the cold, providing light, cooking food to render it more digestible and pathogen-free, and smelting metals. Immediately after the collapse you won't need wilderness survival skills like rubbing sticks together to ignite tinder. There will be plentiful boxes of matches in corner shops and homes, and disposable gas lighters will continue to work for years.

If you can't find matches or lighters, there are less conventional methods for starting a fire using scavenged materials. If it's a bright day, sunlight can be concentrated into a hot

focus using a magnifying glass, a pair of glasses,* or even the curved base of a drinks can that has been polished with a square of chocolate or dab of toothpaste. Sparks can be generated by touching together jump leads attached to an abandoned car battery, and wire wool scavenged from a kitchen cupboard will ignite spontaneously when it is rubbed against the terminals of a 9-volt battery liberated from a smoke detector. There will be an abundance of excellent tinder lying around deserted human habitations, such as cotton, wool, cloth or paper, especially if you douse it in a makeshift fire accelerant like Vaseline, hairspray, paint thinner or simply a drop of petrol. And you won't struggle to find fuel to burn, even in an urban environment. Populated areas are packed with combustible materials, from furniture and wooden fittings to garden shrubs, that can be thrown on a fire for heat and cooking.

The issue is not starting a fire or keeping it going, but where to make it. The vast majority of recently built houses and apartments have no working fireplace. If need be, you can safely contain a fire within a metal bin or bring a barbecue indoors, or if the apartment has a concrete floor you could rip away a patch of carpet and light a fire directly on the concrete. You'll need to allow the smoke and fumes to escape through a slightly opened window (especially if you're forced to resort to combusting synthetic fabrics or furniture foam). But your best bet would be to try to find an older cottage or farmhouse which is appropriately equipped to be heated by fires rather than radiators – this is one of the major incentives to abandon the cities as quickly as possible, as we'll see in a while.

* Although only those for correcting long-sightedness: the concave lenses for short-sightedness, which affects most people, disperse the light rays rather than focusing them. William Golding famously made this mistake in *Lord of the Flies*, with the short-sighted Piggy using his spectacles to start fires.