OUR BIGGEST EXPERIMENT

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Introduction: Experiments

It was Eunice Newton Foote, a scientist, inventor and women's rights campaigner living in Seneca Falls, New York, who in 1856 first warned the world that an atmosphere heavy with carbon dioxide could send temperatures soaring. At the time, no one paid much attention.

Her experiment was reasonably simple. She placed two glass cylinders by a window and planted a thermometer in each of them. Using a pump to remove some of the air from one of the cylinders, she found it didn't catch the heat as well as the other. From this, she figured out the density of the air had an impact on the power of the Sun's rays. This made sense – after all, everyone knew it was colder at the top of high mountains. After comparing a cylinder of moist air with one that had been dried, she found the Sun's rays were more powerful in damper conditions. This wasn't surprising either, as she commented in her notes: 'Who has not experienced the burning heat of the Sun that precedes a summer's shower?' Thirdly, and crucially for our story, she tried filling one cylinder with carbon dioxide. This had the biggest impact: the cylinder became noticeably much hotter and took a lot longer to cool down after the experiment had ended. She concluded, almost in passing: 'An atmosphere of that gas would give to our Earth a high temperature.'

Her husband Elisha was a lawyer, but also undertook science experiments at home and would collect weather data for the local area. That summer they travelled together to the annual meeting of the American Association for the Advancement of Science (AAAS), held that year in Albany, New York. The astronomer Maria Mitchell had become the first female member of the AAAS a few years before, in 1850, but the titles of 'professional' or 'fellow' were still usually reserved for men. The dominant idea of what made for an authoritative 'proper' scientist of the time was still very male (just as it was almost exclusively white), and it's striking that although Eunice's paper, 'Circumstances affecting the heat of the Sun's rays', was presented at the meeting, it was read for her by a man. In contrast, Elisha presented his own paper. Eunice's paper was read by none other than Joseph Henry, the first secretary of the Smithsonian Institution, so it's possible he was chosen simply to give the paper more prominence. In his introduction, Henry made what were described in the press at the time as 'gallant remarks in regard to the ladies', describing Eunice's experiments as interesting and valuable. Still, if he was impressed by her work, he seems to have forgotten about it after the AAAS packed up for the year, as there's no evidence of him celebrating it later. Henry, much like everyone else who read Eunice's paper at the time, seems to have been interested at first before letting it drop entirely from his mind.

A few people did take note of Eunice's paper. There's reference to it in the *Scientific American* write-up of the AAAS meeting, albeit under the dismissive heading 'Scientific ladies'; reports in the *New York Daily Tribune*; and mentions in Canadian, Scottish and German journals. Her paper was also published in the *American Journal of Science and Arts*, alongside Elisha's far less significant work on a similar topic. Elisha's paper was republished in the London-based *Philosophical Magazine*, but whoever picked it must have taken a pass on Eunice's. A fire at the Smithsonian in 1865 destroyed much of the couple's work and saw Eunice's research on carbon dioxide reduced to a few scant references, largely forgotten until 2011 when retired petroleum geologist Ray Sorenson stumbled across it. A few years later, climate scientist Katharine Hayhoe dug it up after a colleague asked why there were so few women in the history of the field. This in turn saw it reported in the climate change press, where the story of a forgotten female scientist who had found a link between carbon dioxide and a warming climate back in the 1850s hit a nerve. And yet, for Eunice and her contemporaries, it was all theoretical, a contribution to our burgeoning understanding of gases and heat. It would be another century before anyone started to worry about it.

In 1956, oceanographer Roger Revelle was one of several American scientists looking at the topic of carbon dioxide relative to climate change afresh. In the intervening years, there'd been a little more scientific research on the topic. There'd also been a lot more carbon dioxide emitted: the problem was rather less abstract for Revelle than it had been for Foote. He'd been studying the ways in which oceans absorbed carbon dioxide and realised it wasn't nearly as much as had initially been imagined. Moved by the consequences of his findings, he concluded his paper with a note that humanity was carrying out 'a large scale geophysical experiment.' At first Revelle saw this experiment with the Earth's climate as a bit of an adventure, as just a fleeting moment in time – telling Congress in 1956 that it was 'an experiment which could not be made in the past because we didn't have an industrial civilisation and which will be impossible to make in the future because all the fossil fuels will be gone'. Like many other scientists of his time, Revelle believed nuclear energy would supersede fossil fuels in a few decades, solving the problem. But that was one prediction he was wrong about. As the 1960s and 1970s rolled on, the evidence for global warming mounted. People started to worry too. But they didn't turn down the gas – quite the opposite.

Revelle's 'experiment' line would be repeated many times, including by UK Prime Minister Margaret Thatcher in an autumn 1988 speech to the Royal Society: 'We have unwittingly begun a massive experiment with the system of this planet itself.' By this point, Revelle and his colleagues had studied further (and checked and rechecked each other's work) and there was a strong scientific consensus that if carbon emissions continued at their current rate, global temperatures would get very uncomfortable by the twenty-first century. Today, we're living in that uncomfortable future that people in the 1960s, 1970s and 1980s used to worry about. Although there's been progress when it comes to clean energy technologies and mechanisms for building climate policy have been set up (the UN climate convention, for example), most people living on Earth are a long way from safe.

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For anyone who needs a quick recap on the basic science, the way in which the Earth's atmosphere traps some of the Sun's energy is usually called the greenhouse effect. Strictly speaking, greenhouse isn't the best metaphor and it's more as if the planet is wrapped in an insulating blanket of gases. Still, somewhere along the way someone said 'greenhouse' and it stuck. The main gases in this imaginary greenhouse are water vapour, carbon dioxide, methane, ozone, nitrous oxide and CFCs. In some respects, the blanket they provide us is a good thing. Or at least life as we know it has developed under a specific mix of greenhouse gases that keep the Earth at a cosy average temperature of 14°C. Lose this blanket entirely and it'd be nearer -18°C. Mess with the delicate chemistry of the atmosphere even a little, and the complex network of life that's grown up inside this particular greenhouse – the complex network we're part of – starts to falter.

Today, when politicians, scientists and campaigners talk about the danger climate change poses they tend to use the relatively heavy milestones of 1°C, 1.5°C or 2°C global warming (or, if they really want to scare you, 4°C, 5°C or 6°C). One or two degrees might not seem very much, but the figure isn't the difference between when you checked the weather forecast this morning and then later that afternoon. Rather, it's a combination of all the temperatures across the world for the whole year. As such, it can mask many other, more extreme weather events. The comparative warmth they're looking at isn't compared with the year before, but a 'pre-industrial' baseline of the years 1850–1900. They use this baseline because the warming we're talking about isn't just the sorts of climate fluctuations that would be happening whether humans lived on this planet or not, but has been caused by the massive influx of greenhouse gases into the atmosphere since the Industrial Revolution.

The biggest perpetrator of this industrial warming is carbon dioxide, mainly from the burning of fossil fuels. Carbon emissions have also risen due to the destruction of natural 'carbon sinks' such as forests cleared to graze livestock which would otherwise breathe in our emissions. This part of the problem began well before the Industrial Revolution. Indeed, there's evidence that the emergence of farming several thousand years ago saved us from another ice age. Industrial activities have released other greenhouse gases too, like methane, CFCs and nitrous oxide. The fossil fuel industry causes methane emissions, for example, along with carbon, as do livestock (cow farts often get the blame here, though it's more the burps we should be worrying about). And in case you were wondering, yes, those silver canisters of nitrous oxide contribute to climate change too, although the nitrous oxide emissions from agricultural fertilisers and manure are a much larger problem.

One of the many slippery things about the climate crisis is that it doesn't hit people with a clearly identifiable thud. It creeps up gradually over time and does so mixed in with all sorts of other aspects of our world; other problems humans have made and hazards that were already waiting for us. This mixing with other problems is partly what makes the impacts of climate change so hard to predict, but it is also what makes them so toxic. Climate change takes a host of other social, economic and environmental issues, and turns up the heat. It adds new hazards to trip over, squeezes already pressurised systems and further exhausts already depleted resources. As climate scientist Myles Allen puts it: 'People ask me whether I'm kept awake at night by the prospect of five degrees of warming. I don't think we'll make it to five degrees. I'm far more worried about geopolitical breakdown as the injustices of climate change emerge as we steam from two to three degrees.'

The American state of California offers a good example of how the climate crisis tightens the grip of other injustices. Teams of prison inmates – many on minor drug offences and including youth offenders – are sent to fight wildfires for a dollar an hour and the promise of credit towards early parole. This has happened since the 1940s, but as wildfires get worse, the state relies more and more on this cheap, captive workforce. It's been estimated the program saves the state nearly a hundred million US dollars a year. And that's just the tip of the speedily melting iceberg. We can't tell for sure if the 2014–16 Ebola breakout in West Africa was caused by climate change shifting bat populations, but it's likely we'll see more of these interactions in the future as the pressures surrounding rising temperatures push people and other animals closer together. The same can be said about mosquito-borne diseases like Zika or malaria. There's no evidence linking climate change to COVID-19, but it could well mean we see more pandemics, deadlier ones, spreading faster. There's also plenty of research showing that as temperatures rise, so do instances of violence, be that rape, domestic violence or civil war. And, in case you were wondering, Harvard researchers reckon climate gentrification has been discernible for a few years already too, as the rich push the poor out to riskier land.

Greenhouse gas emissions can go down as well as up. As Mark Maslin and Simon Lewis stress in their book on the Anthropocene (the geological era characterised by the impact of humans), *The Human Planet*, there is a noticeable dip in atmospheric carbon around the start of the seventeenth century. Maslin and Lewis trace this back to the colonisation of the Americas a century or so before, or more precisely the deaths of 50 million indigenous people. The dead don't farm and so the unmanaged land shifted back into forests, which in turn inhaled enough carbon dioxide for it to be in bubbles of air from the time preserved deep in the polar ice caps. This regrowth was short lived. European settlers in North America soon got to farming for themselves, not to mention coal mining, inventing kerosene and laying railway tracks, highways, and oil and gas pipelines. Still, this temporary drop in carbon dioxide levels might well have played a role in the so-called 'little ice age', a series of cold snaps between, roughly, 1350 and 1850. This little ice age most likely had a mix of causes – dust from volcanoes intercepting sunlight, for example – but the regrowth caused by colonialism of the Americas might well have been one of them; human forces combining with those from other parts of nature to shift climates, just as they do today.

The little ice age wasn't cold enough to be a true ice age, but it was cold. The carnivalesque end of this involved frost fairs, puppet shows, ox roasts and children playing football on the thickly frozen ice. There are stories of frozen birds falling from the sky, Henry VIII sleighing between palaces, New Yorkers walking from Manhattan to Staten Island and even an elephant being led across the Thames. It's one reason Stradivarius violins are so prized; trees during this period took longer to mature in the cold, making denser wood and thus a very particular quality of sound. The darker side of this mini ice age was people shivering to death. Whole villages in Switzerland were destroyed by growing glaciers. Prolonged cold, dry periods had an impact on crops and livestock. People starved. Some environmental historians spin this as a warning from history, tracing the changes in weather to a rise in anti-Semitism and the witch-hunts as well as several wars. There were winners – there are always people who can make an opportunity out of a crisis – but only off the back of a lot more suffering elsewhere. People in the mid-seventeenth century believed they were living in truly awful times. And, unlike pretty much every other generation that's made that complaint, they had a point. Still, that's nothing compared with what could be in store for people born in the twenty-first century.

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This book tells the story of how we found ourselves in the middle of Revelle's big, geophysical experiment; how we built systems, technologies and deeply embedded cultures for the burning of coal, gas and oil at scale. Our narrative starts in 1851, the start of this 'pre-industrial baseline' on which those 1.5°C and 2°C warming warnings are based. We kick things off at the Great Exhibition, a big show put on by the British government to celebrate its newly minted industrial power. From there we travel back in time to those cold years of the seventeenth century to understand the roots of the steam age, before moving on through the nineteenth and twentieth centuries, tracing the growth of the oil industry first in the US and then Russia. We'll see the first oil wells drilled in Borneo, Iraq and the Niger Delta, and oil cartels move from inter-war chats over pheasant shooting in the Scottish Highlands to more complex geopolitical deals leading to a crisis at American gas stations in the 1970s.

We'll see the monster of big oil slain by a plucky investigative journalist back in the 1910s, only to re-emerge even more powerful. We'll follow the growth of electricity networks, how the sparks saw off oil and gas in the lighting industry, before going on to market a plethora of electrical devices to further wire up our homes and offices. We'll also see electricity lose out to oil in the battle for transport, at least for the twentieth century. We'll see excitement over solar and wind power start in the 1870s, only to be forgotten about but then rediscovered in the 1970s and finally come of age at the start of the twenty-first century. Throughout, we'll watch an environmental movement grow to fight the dangers of this industrialisation. As we'll see, this movement would be a mixed bunch, folding a variety of ideological takes into environmentalist concerns, from anti-capitalist revolution to white supremacy (as well as a desire to simply breathe more easily).

At the same time, we'll trace the intersecting story of how we discovered the climate crisis was happening in the first place. In some respects, this is the more hopeful end of the story, reflecting humanity's ability to understand itself and the world around it. This strand starts around the same time, rooted in the mid-nineteenth century, with the odd look back to see how we got there. As we'll see, the discovery of anthropogenic global warming didn't arrive in a single 'eureka' moment (or even a single exclamation of 'oh, shiiiiit') any more than the fossil fuel age started with a singular bang. No one woke up one day, looked out of the window, slapped their forehead and exclaimed that burning fossil fuels makes the weather dangerous. As with most science, understanding of the climate crisis unfolded reasonably slowly, with each generation adding their own take.

It took time for people to process what they'd found – emotionally as much as anything else – to appreciate its impacts and causes, to question it, interrogate the gaps in their knowledge, check it was true and link it up with other bits of research that might tell us more. It also took time for this new science to be understood and absorbed by the rest of society, making its way, like any new bit of knowledge, from one laboratory to another, to newspapers, political speeches, chatter over dinner, protests, poems, playgrounds and, eventually, people's everyday way of seeing the world. Some of the slow pace of this gradual unfolding is understandable – annoying, frustrating, losing us valuable time, but also the way science, technology and political systems were set up to run – but some of it was deliberately, mendaciously kept slow too. The oil industry didn't start deliberately spreading doubt about climate change until the late 1980s, but it did spread doubt. We can lay the blame at its feet for at least a chunk of lost time.

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I'm not going to offer you villains and heroes. This is not a simple story with evil exploitative fossil-fuel baddies on one side and the goodies of renewable energy, environmentalism and climate science on the other. It's more complex than that. What's more, although individual characters played roles that we might, more or less, count as either villainous or heroic, none of them worked alone. The climate crisis is a social project – one that's always been more about the impact of groups of people than individuals.

Spencer Weart puts it well in his 2003 book *The Discovery of Global Warming*, noting that a statement as simple as 'last year was the warmest year on record' is the work of a massive, multigenerational, international effort. Weart means in terms of the many people involved in spotting that shift in global temperature, in building the science that lets us see that far, but we should be aware of the massive effort behind the cause of that warming too. People have only managed to heat the planet to the point they have because they work together. You can play with the idea of a personal carbon footprint if you want, but nothing especially 'high carbon' is done alone. You can drive an SUV on your own, for example, but you still need to buy it from a company and buy petrol from another. Moreover, it was built by multiple hands, using materials mined by others, drawing on the knowledge of generations of engineers, and that's without tracing through networks of advertising, design or the road infrastructure.

In all this, it's vital to remember some people had more of a role in creating the climate crisis than others, and some people are more able to insulate themselves from the dangers too. As Tim Gore, Oxfam's former policy lead on climate change, points out, the poorest half of the global population are responsible for only around 10 per cent of global emissions and yet live overwhelmingly in countries most vulnerable to climate change. So, I invite you to explore 'our' biggest experiment, but to do so critically. We should be aware of our shared humanity and shared planet, as well as the ways many people have worked together over time to create this problem (and how many people will have to work together to undo it). But we must also be mindful of how weighted our social systems are and the inequalities at play; how many people have been excluded, not just in the past but in the present and future too.

It's also worth giving the health warning that this is a story about a lot of white men, many of them rich, and that much of the activity of the book happens in the US and UK. The climate crisis has been and remains a problem of the elite's making, and so it's the powerful we follow to understand how it happened. As the story develops we'll see everything become more globalised. We'll see bigger and more complex trading routes emerge, all chugging out new reasons to burn through fossil fuels in the process. With increasing globalisation, we'll also see an emergence of thinking about the world as a whole, rather than just small bits of it. But that doesn't mean the whole world is working together as equals. Today the idea of thinking about the planet as one is often associated with the sort of hippie ideals of world peace, love and understanding. There's a big difference between a whole- planet approach based on people working together through cooperation and in harmony with nature – the happy, utopian one used by fizzy drinks' ads – and one rooted in more militaristic traditions of control. Both shape our modern conception of the climate crisis and both are likely to continue to be part of how we weave through our warmed future, so it's worth being attuned to them.

Writing this book has, at times, been painful. I would come home from my day job working for a climate charity, supporting my colleagues fighting for a liveable future, and then bury myself in stories of people in the 1770s thinking burning more coal was simply a great way to make more money; others expanding oil drilling in the 1890s; or scientists in the 1970s dismissing the year 2000 as far enough in the future that we didn't need to worry about carbon emissions yet. Sometimes it was hard not to simply shout 'WELL, FUCK YOU VERY MUCH' at whatever source I was taking notes from. Still, it's also been an uplifting experience on occasion too, not least the parts about the history of climate science. And it's certainly helped me understand the climate crisis more fully.

The story of the climate crisis is, undoubtedly, the great tragedy of our time, but it's a story of a lot more than that too. It's the making of our modern world, for good as well as bad. For those of us who live in rich countries, it's easy to take the flicking of a light switch for granted, but we have access to illumination (along with heat, food and transport) that our ancestors could only dream of, access that everyone should be able to enjoy. It's a story of great minds, the pursuit of truth and courageous attempts to make the world better (as well as a dose of eccentricity and whimsy). It's also a story steeped in colonialism, full of inequality, spin, snobbery and hubris. It showcases some of the best of humanity as well as the worst, and may well be the end of us. I've found researching this book a rip-roaring ride and hope you enjoy reading it, even if you find living through the climate crisis a rather less pleasurable experience.

CHAPTER ONE

A Steam-Powered Greenhouse

It's only apposite to start our story inside a giant, overambitious Victorian greenhouse. The Crystal Palace must have been quite dazzling to see up close. A vision in cast iron and plate glass three times the size of St Paul's Cathedral, it covered almost a million square feet of Hyde Park, enclosing four mature elm trees. Created for the Great Exhibition of 1851, the whole thing had been built in rather a rush, with ambition much larger than the deadline or budget allowed. Led by Queen Victoria's husband, Prince Albert, and innovator Henry Cole, the idea for a great, British exhibition had been inspired by similar, though smaller, events that had been running in Paris since the start of the century. The idea hadn't been universally popular at first, but once it opened the critics were, on the whole, proved wrong. Some 25,000 people flocked to the opening on 1 May 1851. By the time the cast-iron doors closed again five months later, 6.5 million visitors had passed through the crystal halls. Allowing for foreign and repeated visits, historian Jeffrey Auerbach estimates a fifth of the British population would have attended the exhibition. Up-and-coming travel agent Thomas Cook arranged special excursion trains, school groups poured in and there's even a story of one woman walking all the way from Penzance.

Based on greenhouses designer Joseph Paxton had previously built for the Duke of Devonshire, the palace's distinctive fan-shaped facade was said to have been inspired by the large ribbed leaves of Amazonian water lilies. Paxton had won fame and a knighthood when he pioneered the growing of these lilies in the UK, replicating their natural warm, swampy habitat with manufactured heat from coal-powered boilers in his greenhouses. He had also noticed the lily pad's seemingly delicate leaves were strong enough to hold the weight of his young daughter (inspiring a brief craze for balancing children on the plants) and put that knowledge to use in the palace design. The 'crystal' walls had been made possible by a new process for producing sheet glass developed in the West Midlands a few decades before, with nearly 300,000 planes of glass shipped along the canal to the building site in central London. Once the various pieces were on site – the glass, as well as iron and wood guttering – a fleet of 75 specially built glazing wagons fitted it all together, with giant lanterns and bonfires of scrap timber allowing workers to keep going well after sundown.

A stained-glass window in the upper galleries filtered the sun in all the colours of the rainbow, and at the centre of the excitement was an iconic crystal fountain, 27ft high, made of 4 tonnes of pink glass. J. J. Schweppe & Co won the catering contract, supplying 2 million Bath buns and more than a million bottles of their relatively new product, artificially fizzing water. When it came to the exhibits, *The Times* calculated you'd need to spend at least 200 hours inside the palace to see each and every one. It contained a diverse perfusion of delights, but all these exhibits had one uniting theme: the awesome power of technology. Although there was a section on fine arts, it was something of an afterthought and the focus was very squarely on the new machines of the age and the raw materials that fed them. For the exhibition's developers, the relationship between science, technology, the Empire and the Earth seemed so simple. 'Science discovers these laws of power, motion and transformation,' Prince Albert told a banquet in March 1850, and 'industry applies them to the raw matter which the Earth yields us in abundance' (no questions to be asked about how the British might have come across raw materials not found within their own islands).

There was iron from Ireland, tin from Cornwall, cedar wood from Cuba, cocoa from Trinidad, tobacco from America, cinnamon from Ceylon and whale oil from the 'South Seas'. Visitors could learn about the history of the steam engine via a special display in the stand run by the Birmingham-based firm Boulton & Watt. There were also displays on the production of steel and cotton, a device for folding paper, a cigarette-rolling machine that produced 100 cigarettes a minute and a printing machine that turned out 5,000 copies of the *Illustrated London News* an hour. You could buy one of the very first weather maps, produced by Greenwich Royal Observatory's superintendent of meteorology James Glaisher, which utilised data that came via a network of amateur weather watchers who sent it to London via the new electric telegraph. Some of the exhibits were more mundane, featuring the sorts of things middle-class visitors to the exhibition might see in shops or have in their own home: cutlery, chairs, mirrors, clothes and curtains. Other displays showcased ideas for new products; items their designers hoped would become commonplace in years to come. There was a carriage drawn by kites, an early version of the fax machine, false teeth that didn't fall out when you yawned and special furniture designed for steamships that combined a bed with a toilet and could be repurposed as a raft.

When the Great Exhibition is remembered today, it's often as a celebration of science and technology, but really it was about a whole host of things: from giving the Queen's husband something to do, to selling forks, fur coats and fizzy water. Perhaps above all the whole exercise was an expression of imperial power at a time when the English ruling classes were increasingly worried their privileged position in the world might be about to shift. The East India Company (EIC)[1] was provided space in the centre of the galleries devoted to the British Empire, with the commodities of each colonised country shown off for the wealth they provided. This included the infamous Koh-i-Noor diamond, which inspired the detective novel *The Moonstone* and now sits in the Tower of London as part of the crown jewels (despite the governments of India, Pakistan and Afghanistan all claiming ownership). There were also domestic concerns, with an increasingly rebellious British working class pushing for greater share of national prosperity. Tied up in this vision of British supremacy was a celebration of how much British science and technology had developed in the past 50 years or so, and what might come next. It was an indication that life had changed in the UK and was on course to change elsewhere too, with a clear message that this change was unquestionably for the good and those currently in control of the new machines should stay exactly where they were.

And at the heart of all of this was coal. Coal was there in the raw materials' section of the palace, with 18 large lumps of the stuff drawn from fields across the UK, including a chunk from South Wales whose slow trip down to the exhibition site had been reported in detail by the newspapers. Coal also powered the machinery section, via a set of coal-fired steam boilers in the north-west corner. Coal smoke was therefore presumably perfuming the air inside the exhibition too, and the increasingly thick smog of London would have certainly been noticeable to visitors from out of town. Moreover, coal-powered steam would have produced many objects on display at the exhibition, and at least half the visitors would have come by coal-powered trains or on coal-powered boats along the river. Coal was also symbolically front and centre, with that lily-pad design of the frontispiece inspired by Paxton's use of coal-heated greenhouses to grow plants taken back from far-flung parts of the Empire.

Through its various articulations of coal, the Crystal Palace and its contents reflected the start of something new: an age of prosperity for some, built on the burning of fossil fuels. And this is why we start with the story of Joseph Paxton's glass creation; a swollen greenhouse in the centre of London, filled to the brim with machines of the steam age, bourgeois trinkets and resources from around the world often seized by colonisers powered by coal. It reflects a pattern of progress that the world was to follow deep into the environmental crisis we find ourselves in today. The Great Exhibition didn't invent consumer culture or the burning of fossil fuels on a mass scale any more than it invented colonialism. Still, it reflected the establishment of a way of life that would become our modern climate crisis.

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Britain may have led the world into the climate crisis via coal, but they weren't the first to burn it in an organised way. Modern radiocarbon studies suggest people in Inner Mongolia and the Shanxi provinces of northern China were using the fuel more than 4,000 years ago. Then, a few thousand years later, the Northern Song Dynasty in eastern China developed what might be seen as the first fossil fuel-based economy, burning coal to produce iron, gunpowder and ceramics, as well as heat homes. But the power of Northern Song ended when its capital was invaded in 1127, its use of fossil fuels falling by the wayside at the same time. In Europe, the Romans made use of British coal reserves soon after they invaded in the first few centuries ad, setting up coal-trading routes across their empire, using it to heat their homes and garrisons, work iron, process salt and to keep the perpetual fire alive at the Temple of Minerva in Bath. But the British themselves weren't exactly enamoured with the stuff. Coal's polluting effects are pretty obvious even without any awareness of the greenhouse effect. It leaves sooty marks and gets into your chest. This is especially true of English coal, which tends to be the soft and sooty bituminous type. In 1285, Edward I set up the world's first air pollution commission, banning the burning of coal in London. The ban was often flouted, but coal was far from mainstream. When people could afford it, they burnt wood.[2]

But as the years went on, wood became scarcer. The forests that had once thickly coated the British Isles were sucked up to clear land for agriculture, with the wood used to build houses, roads, bridges, ships and barrels to help in the production of all the salt, lead, glass and beer people were consuming, as well as to simply keep homes warm. This was a political worry – the navy needed wood for ships to fight Spain and explore 'the New World' – and Elizabeth I set up several official investigations into the loss of

England's forests. And as the price of wood rose, coal became more attractive. By the middle of the sixteenth century, coal had become an established part of London life. It would have been known as 'sea coal' back then, as it could be found on the beach having fallen from exposed coal seams on cliffs or washed up from underwater deposits. It would come into London up the River Fleet, a now-buried tributary of the Thames, having travelled around the coast of Britain. You can still find a small alleyway half a mile north of Blackfriars Bridge called Old Seacoal Lane, noting the point it would have come into the Fleet. Coal still wasn't universally popular, but it was burnt in homes, blacksmiths, potteries, bakeries and glassworks. Brewers became great users of coal, as did salt boilers (key to preserving food in an era before refrigeration). Soap boilers used it too, as did lime burners and sugar refineries. Although parts of the economy still relied on wood, water or animals for energy, an age of fossil fuels had begun.

This was all still relatively small scale compared with what was to come. Indeed, humanity might have crept along with the relatively slow burn of global warming caused by the impacts of agriculture and the odd coal fire if it wasn't for the development of the steam engine. This piece of kit was first sold commercially to help pump water from mines – a way of making coal mining slightly easier – but gradually found uses elsewhere. It thus opened up a much larger market for coal, paving the way for oil and gas industries too, and supercharging our ability to warm the Earth in the process. The first steam engines date back to antiquity. Around the first century in Roman Egypt, Hero of Alexandria developed an 'aeolipile' – a device attached on top of a cauldron that used steam to make a ball spin – which was used largely as a toy. There are whispers of people having more practical ideas for steam-powered devices after this. Basque engineer Blasco de Garay, for example, had an idea for a steam-powered boat back in 1543, but Carlos I didn't want to invest, so it remained just a sketch.

Then, into late-seventeenth-century London, arrived a refugee – indeed a member of the French Huguenot community for which the word 'refugee' was coined – Denis Papin. Papin had already worked with German mathematician Gottfried Wilhelm Leibniz in Paris, and soon found work at the Royal Society as a laboratory assistant to founder member Robert Boyle. Boyle was an established expert on the pressure of gases and Papin worked with him on experiments involving steam, presenting what he called the 'Steam Digester for softening bones' in 1679 – a pot that utilised steam to cook tough foodstuffs (or to put it another way, he invented the pressure cooker). The Royal Society wasn't exactly enthusiastic about Papin's work, repeatedly treating him more as a servant than an equal and refusing to promote him or fund further steam work. Unable to return to France, Papin moved to Vienna briefly and later Marburg in Germany, continuing his experiments on steam and developing ideas for machines that would use steam power not just to cook, but for movement. He returned to London in the early eighteenth century, but the Royal Society still wouldn't support his steam research. He's thought to have died in poverty in 1713, buried in an unmarked grave in St Bride's Church, just the other side of the road from Old Seacoal Lane.

Military engineer Thomas Savery had more luck showing off his version of a steam engine to London's scientific elite, demonstrating it to Royal Society members in 1699. Savery promoted his device as a way to drain mines, describing it as 'the miner's friend', but it wasn't very efficient, requiring almost as much coal as you'd get out of any mine that used it. Plus, mine owners were worried about the danger of bringing fire to their site, concerned it'd ignite gases found in their tunnels. One thing Savery was really good at, however, was securing intellectual property rights. He patented an invention for 'raising water by the implement force of fire', and speedily secured an Act of Parliament that extended this patent all the way through until 1733. This rather aggressive patent strategy arguably stalled the development of steam power as it kept others out of the game. Still, some developers managed to work with Savery's patent, notably the lay-preacher and ironmonger Thomas Newcomen. His more efficient version of a fire engine borrowed from Savery and Papin, as well as incorporating ideas of his own. Newcomen partnered with Savery to accommodate the patent and by the 1760s there were hundreds of Newcomen engines dotted around mining areas of the UK, soon shipping to other parts of Europe and America too.

If draining a colliery using horses cost £900 a year, a Newcomen engine could do it for £150. Still, they were the size of a house and required a lot of coal to keep running, all overseen by a 'fire man' whose job it was to feed this hungry machine. It was only worth it if you had a healthy supply of coal nearby: fine if you were using it in a coal mine itself, but the costs could soon rack up if you had to transport it anywhere else. Again, we might have stayed there; a medium-sized coal industry helped along by a few Newcomen engines fuelling a slightly more intense burn of global warming. But a new era of steam engines from Boulton & Watt was to change that, offering a cost-effective replacement for water- and horse-powered wheels that could be put to a range of tasks, opening up a massive new market for the burning of fossil fuels. Before long, coal-powered steam was not only powering factories, cotton and flour mills, but also trains, boats and cars, inspiring a host of technologies and infrastructure the oil and gas industries would later build on.

* * *

James Watt's story starts in a British port in the middle of the eighteenth century – and like many such stories it owes a debt to the slave trade. Watt's family didn't have the wealth of the British upper classes of the time, but they had enough to ensure young Watt had a comfortable childhood and education, with books at home, and even a small forge specially built for him in his father's workshop to allow him to learn wood and metalwork skills. Watt's father worked in shipping, trading in rum, sugar and cotton out of Greenock, a port 20 miles to the west of Glasgow. In 1755, when Watt was in his late teens, he moved to Glasgow to train to be a maker of nautical and scientific instruments.[3] He had good contacts at the university, where his cousin was a professor of Latin, and he knew the professor of natural philosophy, John Anderson, from school. Soon after Watt arrived in Glasgow, a large collection of scientific equipment was donated to the university by Alexander MacFarlane, a slave-owner in Jamaica. Watt was given the job of fixing the salted-up loot once it had crossed the Atlantic. Although this was piecemeal work, he could make a living as an instrument maker and fixer for the university. He eventually had an apartment and workshop on site, supplementing university work selling scales, balances and compasses to his father's customers in shipping, and eventually his own clientele too. Watt opened a shop in the city centre, employing 16 men, selling and fixing everything from shoe buckles to pistons, nutcrackers, violins, flutes and bagpipes. This story is often told as a geeky Watt finally finding business acumen when he teamed up with the more outgoing Matthew Boulton, but Watt was doing pretty well on his own before that partnership.

Glasgow at the time was growing rapidly, boosted by slavery via the trading of rum, sugar and cotton. Interest in science, engineering and philosophy was growing off the back of these new riches, and the city was busy with intellectual, industrious chatter. Anderson ran what he called 'anti-toga lectures' in the evenings, where local skilled workers could study. Along with Edinburgh, Glasgow also boasted several 'irregular clubs' where men like Watt could swap ideas over food and drink with other thinkers of the time, and it's through one of these that he met economist Adam Smith and scientist Joseph Black. Fresh from his discovery of carbon dioxide, Black had been appointed professor of chemistry at Glasgow in 1757. After local whisky distillers asked his advice on cost-cutting, Black had gone about investigating how chemicals changed state from solid to liquid or gas (and vice versa). How did water absorb heat to become gas? Why doesn't ice melt into water straight away? He developed the idea of latent heat, arguing that a certain amount of heat would be needed by any material before it could transform. Black's questioning of the nature of heat, along with his friendship and support, was key to what Watt would work on next and would help him make steam engines more efficient.

It's often said Watt was introduced to steam engines when Anderson gave him a model Newcomen engine to fix in 1764. In fact, he'd been working with steam for a few years by then, having first been introduced to it by John Robinson, another physicist he'd befriended in Glasgow. Decades ahead of his time, Robinson was excited by the prospect of replacing horse-drawn carriages with steam engines and had published a design for an improved Newcomen steam engine back in 1757. Watt was equally intrigued by the power of steam and, inspired by Robinson, experimented with Papin's Steam Digester designs. The model Newcomen from Anderson's collection gave Watt something physical to tinker with. He worked out he could waste a lot less heat than the Newcomen system by adding a separate condenser. His work was supported further by investment from a John Roebuck, an old student of Black's who was looking for more efficient engines to use in the coal mines he'd bought near Bo'ness.

It was through this project with Roebuck that in the summer of 1767 Watt visited Birmingham and came into contact with a group called the Lunar Society. Like Glasgow, Birmingham was brimming with talk of science, engineering and philosophy, enriched by the growth of local industry and the many nonconformists who had settled there (that is, people who didn't 'conform' to the Church of England). Birmingham didn't have a university, but its intellectual community was none the worse for it – if anything, it had a positive effect. In England, the choice of university was Oxford or Cambridge and you pretty much had to be a practising member of the Church of England to attend either. Any sniff of the sort of radical politics held by people like Anderson and you might find yourself rather unwelcome too. In the new industrial towns like Birmingham, informal intellectual clubs and academies for religious dissenters thrived, free from such constraints.

The first glimmer of what would become the Lunar Society started sometime in the 1750s in Birmingham. Industrialist Matthew Boulton and local physician Erasmus Darwin had met via mutual friends, hit it off, and started meeting regularly to discuss matters of science and invention over dinner.[4] They gradually picked up other local men or those passing through town who shared their interests in engineering, botany, geology, or the new sciences of gases and electricity. They'd meet once a month for dinner on the night of a full moon, allowing them enough light to get home safely afterwards. The Lunar Society's members weren't aristocrats, but they tended to have some privilege of education, inherited wealth and contacts. Darwin was one of the few to have attended a formal university. After studying at Cambridge he'd trained at the Edinburgh Medical School, but was interested in pretty much anything and everything, from plants to cosmology to women's education. He'd sometimes entertain himself by writing poems about his science, as well as sketching designs for inventions including several for monitoring the weather (he once suggested the transportation of two icebergs to the equator to cool the tropics and so ease northern winters). Boulton was more straightforwardly a man of business, but was no less excited by new science and inventions. He'd inherited his father's firm making small metal goods, then known as 'toys'. Helped by a marriage to a rich heiress (and when she died, her sister) he'd built this up to a large 'Manufactory', which produced a range of precision craft goods from buckles, buttons and intricately decorated vases, to scientific equipment like thermometers and telescopes. Other Lunar regulars included radical preacher and scientist Joseph Priestley; Quaker, gunmaker and banker Samuel Galton; and Irish politician and inventor Richard Edgeworth (whose 22 children included novelist Maria Edgeworth and whose innovations included a proto-telegraph system). There was also the potter Josiah Wedgwood, a master of both chemistry and marketing who pioneered not only several glazing techniques but also money-back guarantees, celebrity endorsement, free delivery, market segmentation and illustrated catalogues.

When Watt first visited Birmingham, he was shown around Boulton's manufactory by Darwin and was amazed by what he saw. Visiting again, he met the man himself and they immediately formed a strong friendship. As well as friendship, Boulton hoped to find a solution to a problem he'd been pondering for a while. For all his manufactory's success, it could get a bit stuck for power. There was a waterwheel in the near by Hockley Brook, but this could dry up in summer or freeze in winter, and they'd have to buy in horsepower to keep everything going. Boulton had been looking into options for a horseless pump, but the coal-guzzling Newcomen was too expensive to run. He'd heard of the improvements Watt had made to steam engines and wondered if it could be the answer, and something he could sell to mills and other manufactories too.

was eagerly transforming every bit of society they could around coal.

* * *

Boulton and Watt took the steam engine out of the coal mines and into the mills, but for the steam age to really get going, these engines had to be applicable to transport. Watt had chatted to Darwin and Robinson about their ideas for steam carriages back when he was developing his static engine, and they weren't the only ones playing with the idea of steam engines for transport. In France, military engineer Nicolas-Joseph Cugnot experimented with steam-powered vehicles as early as the 1760s, as a way to transport cannons. You can still see his steamer car, the *fardier à vapeur*, on display in the Paris Museum of Arts and Crafts. However, after a few tests, including a mishap with a wall of the Paris arsenal in 1771 (arguably the first recorded car accident), the project was abandoned.

The first coal-powered ship set sail as early as June 1783 on the river Saône in eastern France. The Marquis de Jouffroy d'Abbans had taken a Newcomen engine and wooden fan and mounted them on top of a boat; it chugged along at walking pace for 15 minutes before the hull split and the boiler burst in clouds of steam. Wind power was safe when it came to ships, at least for the time being. A few years later, in 1787, American inventor John Fitch attempted to launch a commercial steamship outfit on the Delaware River. So the story goes (and it might well be just a story), Fitch had been captured by Native Americans while exploring the Ohio River valley; haunted by dreams of canoes chasing him, he imagined a steam-powered ship might have helped him escape. Fitch's first steamboat only went at 3mph, but was enough to convince investors it was a good idea and a second ship in 1790 fared slightly better. He started advertising for passengers but, despite rolling up a few thousand miles, never attracted enough custom to warrant the cost of running it. He tried to sell his idea in France and then England, but failed, never building another boat and ending his life in 1797 with a handful of opium pills washed down with a bottle of whisky.

It would be another two decades before anyone managed to really sell the idea of steamships. The man to do this, Robert Fulton, started off working in the arts and spent most of his career in engineering chasing an idea for underwater bombs. Still, he kick-started a steamship industry in the US, which was soon copied elsewhere. After working as an apprentice jeweller in Philadelphia, Fulton moved to the UK in 1787, ostensibly working as a painter but mainly living off the generosity of rich friends. Around 1790, he seems to have changed track. Perhaps infected by the 'canal mania' gripping Britain at the time, or maybe just realising he'd never be a great painter, he started a career in engineering. Suddenly full of inventions for everything from a canal-digging machine to a marble-cutting saw, he was especially excited by his idea of *Nautilus,* a submarine missile that could explode enemy boats from beneath. He also flirted briefly with the idea of a steamship, writing to Boulton & Watt in 1794 to enquire about a three to four horsepower engine and what size of boat it would need (although they never replied).

In 1797, Fulton moved to Paris. Planning to stay just six months, he ended up there for seven years, settling into a relationship with American poet and diplomat Joel Barlow and his wife Ruth.[5] The Barlows took Fulton on as a sort of protégée, giving him the affectionate nickname 'Toot', tutoring him in languages and maths, and lobbying the French government to fund his *Nautilus* plans. Joel dabbled in engineering himself, he'd even taken out a patent for a boiler to try on steamships, and could introduce Fulton to people like ballooning pioneers the Montgolfier brothers. In Paris Fulton also met American diplomat Robert Livingston. A member of the 'committee of five' who had drafted the Declaration of Independence, Livingston had been sent to Paris by President Thomas Jefferson to negotiate the Louisiana Purchase. With an inherited fortune that allowed him to indulge an interest in engineering on the side, Livingston had been percolating an idea for trying out steamships in New York, and in Fulton saw a potential business partner with the engineering sense and entrepreneurial spirit to make this steamship wheeze work.

Many were sceptical, the Montgolfier brothers were dubious this steamship business would ever really work and Fulton himself was more interested in his underwater missile ideas. But, boosted by Livingston's powerful support, he borrowed a steam engine and started experiments on the Seine. They drew crowds, including the Napoleons, and soon l'Emperor himself demanded Citizen Fulton report on his progress. However, Napoleon was evidentially unimpressed, or possibly just more enamoured by the Montgolfiers' balloons, leaving Fulton and his inventions be. The British noticed Fulton's work too, buying up his plans for underwater mines. They proceeded to sit on the idea, however, seemingly more interested in preventing the French from getting hold of the tech than using it themselves. Still, this deal finally got Fulton an audience with Boulton (Watt had retired by then) and with that a steam engine to try out on a ship in New York.

Finally, on 17 August 1807, Fulton's steamship was ready to attempt a trip from New York City to the state's capital at Albany, 150 miles up the Hudson. A crowd had gathered in Greenwich Village, excited by this unusually long boat with weird paddles, which puffed and roared out clouds of dark smoke like some sort of sea monster. Many of the spectators wouldn't have seen any type of a steam engine before and the idea of a steam-powered boat must have seemed quite fantastic. Some, quite reasonably, thought it might explode and were possibly only there in the hope of some fireworks. Still, it didn't explode or sink and, although it wasn't immediately obvious it would be a success, it fared much better than Fitch's attempts, soon carrying 100 passengers a week.

Fulton busied himself adding several more steamboats to his fleet, including *The Paragon*, a 'floating palace' complete with mahogany staircases, silk curtains and a kitchen capable of serving dinner, on china, to 150 guests. He also had his eye on what he had long suspected would be the real prize of American steamships: the Mississippi. He partnered with Nicholas Roosevelt (first cousin once removed of President Theodore) first to research the feasibility of a steamship in these waters and then build a boat to try it out. In September 1811, Roosevelt set off on a 2,000-mile journey from Pittsburgh to New Orleans in a sky-blue steamship, with his wife Lydia, their infant son, a captain, engineer, six hands and a dog named Tiger on board. Fulton had expected the trip would take a month. It took four, during which they not only celebrated Christmas but had to sit through an earthquake, and Lydia – who had been heavily pregnant when they set sail – gave birth. They soon managed to speed things up, and established a regular service to Natchez, a few hundred miles upriver. Fulton died in 1815, aged only 49, surviving just about long enough to see his business start to flourish, and the riches and accolades pour in. A year after his death, a new street running between his two ferry operations on the south-west tip of Manhattan was named 'Fulton Street', the first of several all over the US. By the middle of the century, it was hard to find any stretch of water in America that didn't have a steam service of some sort. Moreover, the tech was key to colonisation of the interior of the US. In the two decades after the first steamboats arrived on the Mississippi, more people moved to the middle of America than the colonies had attracted in the previous two centuries. And when the army beat Native American communities back, they arrived on steamboats, a sad twist on Fitch's nightmares of being captured on the Ohio River.

Steamships quickly popped up around the world. There was a Liverpool to Glasgow steamer in 1815, and the Post Office added steamboats to their runs to Ireland and France in 1820. By the 1830s, there were steamboats crossing between the UK and Spain, and out towards Egypt too. The East India Company (EIC) commissioned two steamships to run from between Suez and Bombay in the mid 1830s, but the EIC's days, by this point, were numbered. The 'free trade' ideas of Watt's old drinking buddy Adam Smith were increasingly influential and in 1833 an Act of Parliament saw the last vestiges of their trading monopoly formally end. Other traders were quick to pounce on the opportunity, not least the Scottish firm Jardine Matheson & Co. Keen to cash in with the disruptive technology *de jour*, the firm sent out a series of steamboats to transport opium from India to China, hoping steam would withstand monsoons better than sails. The Chinese had another way of looking at it, refusing to have this 'smokeship' (and more pertinently, its opium cargo) in their waters. Fights between China and British traders escalated, and the EIC – keen to show it was still the dominant force in the area – sent out secretly commissioned steam warship *Nemesis* complete with rocket launcher. As what became known as the Opium Wars rolled on, Jardine Matheson & Co realised they could simply put opium on a P&O steamer (it helped that James Matheson was on the P&O board).

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Back on land, the first railways weren't powered by fossil fuels. They were simply carriages on rails that cut down friction, making it easier to transport a heavy load like coal or slate. In Australia, the first railway was human-powered, using convict labour, but most railways were pulled by horses, occasionally helped along with wind-powered sails. When it came to adding coal to the mix, people had played with ideas for steam cars for decades, but the first serious innovator in steam-powered land transport was Richard Trevithick. Having grown up in Cornwall and watched steam engines pump water from local tin and copper mines, he'd dreamt of taking it further. When Watt's patent expired in 1800, Trevithick seized the opportunity, taking steam-powered road locomotive the *Puffing Devil* out for a ride on Christmas Eve 1801. He didn't give it a proper steering mechanism though and it ended up headfirst in a ditch a few days later.[6]

Undeterred, Trevithick produced steam locomotives for ironworks, running them on rails so they wouldn't fall into any ditches. With an engine designed by the flamboyant Count Rumford, Trevithick also set up a short-lived steam car service in London in 1803. Run out of a coachmaker's workshop on Leather Lane, this managed several trips down Tottenham Court Road and along the City Road usually at 4–5mph, but sometimes hitting nearer 9mph. For one special outing, Oxford Street was cleared of horses and carriages, the shops closed but upper floors packed with spectators. People were keen to watch the machine puff its way through London, but unfortunately this enthusiasm didn't extend to investment and the scheme folded. In 1808, still trying to drum up some interest, Trevithick set up a steam circus not far from what is now Euston Station. There, a small steam locomotive, *Catch Me Who Can,* moved at 2mph around a 100ft circular track, with passengers paying a shilling to ride. Sadly, not enough people even came to watch. Trevithick turned his back on the locomotive business and boarded a whaling ship to South America, working in mining in Costa Rica and Peru.

Horses remained the default method to power railways, but they could only go so fast before they needed food and rest, plus the work involved meant they often died quickly. For industrialists needing to transport heavy loads, like iron or coal, steam-powered transport seemed worth a try. One of the engineers employed to build steam-powered trains for the mining industry was George Stephenson. Born in 1781 in Northumberland coal country, Stephenson did not have the advantages Watt was born with. Instead, he built them for himself. Young Stephenson started work aged seven, first in farms and then with his father, feeding the mines' steam-powered water pumps with coal. He put himself through night school and learnt to read for the first time in his mid-teens.[7] Then, in his mid-20s, things took a turn for the tragic. His wife and baby daughter both died. He hired a housekeeper to look after his infant son, Robert, and – possibly out of grief but more likely necessity – walked 200 miles north to take a job in Scotland, working with a Boulton & Watt steam engine at a spinning mill. When he returned a year later, he found his father had been badly injured in an engine accident, blinded by steam and unable to work. Times were hard. For a while Stephenson thought about moving to America – to see if the new industries popping up around Pittsburgh's coal could make something of his engine skills – but he decided to stay put. On Saturdays, when the engines were idle, he would take them apart and put them back together, examining each piece as he went to understand how it worked. He was also part of a regular discussion group on mechanical matters, including Trevithick's locomotives. He invested in formal education for his son Robert too, on the agreement that he would, in turn, teach him back.

Stephenson started building steam-powered locomotives to move coal around the mine he worked for, but he really drove steam trains into the mainstream in 1824, when he was appointed chief engineer for a new steam railway planned between Liverpool and Manchester. By this point, there it was formally dissolved in 1874. This was far from the end of British imperialism though, via railways or otherwise. It was just shaped differently. Jardine Matheson & Co bought up land in China for a railway line between Shanghai and Woosung plot by plot, and shipped over a small locomotive in the 1870s, although the railway was later ripped out by the Chinese government, wary of foreign interference. Cecil Rhodes' plan for a railway from Cairo to Cape Town to establish British dominance throughout Africa – first suggested in a *Daily Telegraph* leader in 1876 – was refused funding by the UK government, but he cobbled together investment from various sources, including his diamond company De Beers. Soon, in pretty much any part of the continent in which the British were active, railroads could be found transporting both luxury tourists and valuable minerals.

The growth of railways also led to the next development in steamships. One October evening in 1835 over dinner with directors of the Great Western Railway (GWR), Isambard Kingdom Brunel cracked a joke: why not run the line all the way from London to New York, simply putting the passengers on a steamship at Bristol? His casual remark planted a seed. After dinner, Brunel got chatting to Thomas Guppy, a sugar refiner from one of Bristol's richest merchant families who was one of the GWR directors, and the two discussed the idea long into the night. They knew about earlier attempts to use steam to cross the Atlantic; that they'd mainly relied on wind in their sails and weren't really worth it. But Guppy and Brunel felt engine tech had developed sufficiently that it was worth another go. Within weeks, a handwritten prospectus for a Great Western Steamship Company was being passed around rich and daring Bristolians. Brunel's ship for the Great Western Steamship Company, *Great Western*, was finished in the spring of 1838. A series of mishaps in London meant it lost a transatlantic race to New York to another ship, *Sirius*, but Brunel's creation was generally recognised as the better design (plus it won the race back to Europe). What's more, the competition between the two had attracted crowds of excited New Yorkers. It was fabulous PR. Great Western's ocean ambitions collapsed when the mail contract went to former EIC merchant Samuel Cunard. Still, the business case for transatlantic travel in steamships had been clearly made. The world was getting smaller and burning through prestigious quantities of coal in the process.

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Steam power grew up drenched in the prosperity that slavery and colonialism offered Europeans in the eighteenth century. Trade in cotton in particular shaped the development of trains in the UK and India and steamships along the Mississippi. As steam power grew, it was soon put to work to further ingrain and spread the power of white elites. There's one story at least that bucks the trend slightly, however, and is worth telling as tales like these are too often 'steamrollered' by more dominant narratives. In 1906 Tamil lawyer V. O. Chidambaram Pillai – known by his initials VOC – registered an Indian-owned steam shipping company out of the busy port town of Thoothukudi (in the southern tip of India, then known as Tuticorin). VOC had been following the Swadeshi movement, which was using boycotts of British goods as a form of resistance against imperial rule. He figured that in port towns like his, freedom-fighting had to mean control of the seas. He raised a million rupees, selling shares door-to-door, for the Swadeshi Steam Navigation Company, which would be owned by and for Indians, and run in competition with the Scottish-owned British India Steam Navigation Company. His ship, painted in the colours of the Swadeshi flag and emblazoned with a deliberately provocative nationalist slogan from a Bengali poem, ran between Thoothukudi and Colombo, irritating the British intensely. The British firm fought hard against the competition, cutting prices and at one point giving out free umbrellas in an attempt to sweeten customers. Sadly, this era of steam-powered anti-colonialism was short-lived. In 1909, VOC was arrested for encouraging workers at a cotton mill to strike, and the Swadeshi Steam Navigation Company was liquidated in 1911.[10] Still, as we'll see in later chapters, the new fossil fuel economy would challenge power structures as well as ingrain them, not least through the mobilisation of coal workers. Indeed, the elites knew this a good half century before VOC started selling shares in his steamship company. Arguably the 1851 Great Exhibition put on such an inflated show of Britain's great industrial might precisely because it was worried the old patterns of power were changing.

And what became of that giant greenhouse in Hyde Park? The Great Exhibition was only ever meant to be a temporary event and so closed a few months after it opened. The Crystal Palace was too beautiful to lose entirely and so was rebuilt in 1854 on the top of Sydenham Hill in south-east London, where it acted as a hall for exhibitions, concerts, theatre and the occasional circus. Other countries, keen to emphasise Britain didn't have a monopoly when it came to invention, put on their own shows following the Great Exhibition's model (which, after all, had been borrowed from the French in the first place). There was the 1878 Exposition Universelle in Paris, for example, which included a display of Alexander Graham Bell's telephone and the head of the Statue of Liberty. Or the 1889 equivalent that left the world the Eiffel Tower. We'll drop by the 1893 Chicago World's Fair when we pick up the story of electricity in Chapter Five. The Crystal Palace itself burnt down in 1936, in a fantastic blaze that could be seen for miles around. The ruins remain though. If you ever get the chance to visit on a foggy day, it's a wonderfully spooky sight.

And coal, this chapter's key protagonist? Just as this sooty, incendiary rock was the first fossil fuel to be embedded in modern economies, it may well be the first to go. It is rapidly disappearing from the British electrical grid, so much so that tourist steam railways like the 'Harry Potter' *Jacobite* route through the Highlands have appealed to the UK government to protect their stocks. Still, coal is far from gone. Globally, it accounts for nearly a third of energy used worldwide, playing an especially important role in the production of iron and steel. Moreover, arguably Britain has simply outsourced its personal coal problem, able to dress itself up as a climate leader for quitting the stuff in ways other countries simply don't have the means to. Manufactories like Boulton's may be long closed, but the desire for the sorts of consumer 'toys' he produced has grown and grown. And as Britain imports rather than makes its goods these days, children in other countries choke on the coal smoke that produces the everyday stuff of British life; all shipped in on the descendants of Fulton's steamships.

NOTES

[1] A history of the East India Company is outside the confines of this book, but it's worth noting that they didn't just buy and sell goods, they were at the forefront of British colonisation, with their own army and navy. For more on the EIC, see William Dalrymple's *The Anarchy* (2019).

[2] For more on the story of coal, see Barbara Freese's brilliant *Coal: A Human History* (2003).

[3] Watt's brother John joined their father in shipping and later branched out to directly trading in people too. There's evidence that James Watt himself was involved in the trafficking of a small boy at one point. For an entertaining and clear biography of James Watt that avoids the hagiography all too often applied to him, see Ben Marsden's *Watt's Perfect Engine* (2002). For recent research that pulls out the links with the slave trade, see Stephen Mullen and Simon Newman's 2018 report 'Slavery, abolition and the University of Glasgow'.

[4] Jenny Uglow's *The Lunar Men* (2002) is a chocolate box of a book about these characters, their families and ideas; I highly recommend it.

[5] Letters between the Barlows suggest there was a loving and possible sexual relationship between them and Fulton, though it's hard to tell as they were written in a rather obtuse eighteenth-century baby talk. Whatever it was, the three seem to have had a lot of affection for one another, which continued for the rest of their lives. For more on Fulton, Kirkpatrick Sale's *The Fire of His Genius* (2001) pulls out the social and political contexts and impacts of his engineering work, and Cynthia Owen Philip's *Robert Fulton: A Biography* (1985) offers more details of his personal life, including extracts of the Barlows' letters.

[6] There's a story that they simply left it there and went off to eat goose in a local pub, forgetting that this engine, even in the ditch, contained a large fire (until the inevitable explosion, that

is). For more great stories like these, see Christian Wolmar's history of early steam trains *Fire & Steam* (2007).

[7] Later in life, people fighting the expansion of the railways would use Stephenson's relative lack of education as a slur. Stephenson struggled with spelling and grammar throughout his life, remaining very self-conscious of his writing even when his engineering work had made him internationally famous, only letting close family members see anything he wrote.

[8] One of the many other stories about Brunel is that he aligned the tunnel he built in 1841 through Box Hill (then the longest in the world) so the Sun shone directly through on the 9 April, his birthday. When the tunnel was closed for maintenance in April 2017, GWR staff tested this theory and confirmed that it did seem to have been designed for the sun to rise on that date, at least from the eastern portal.

[9] For more on Chinese labour, see Gordon Chang's (2019) Ghosts of Gold Mountain. Manu Karuka's (2019) book Empire's Tracks also covers this story, alongside those of Indigenous nations.

[10] There's a great telling of this story in Sunil Khilnani's *Incarnations: India in 50 Lives* (2016) (also available as a BBC podcast). Thanks to Justin Picard for the tip.

CHAPTER TWO

Discovering Our Hothouse Earth

Every summer, tens of thousands of people attempt to climb Mont Blanc, the highest peak in the Alps. This number is increasing as the desire to catch a summit selfie grows, bringing less-experienced climbers with it. At the same time, warming temperatures are making such trips riskier. The average temperature in the resort of Chamonix, at the foot of the mountain, rose by more than 2°C over the course of the twentieth century (more than double the global rate). This is not just a matter of glaciers retreating, but also means climbers have to contend with landslides and steeper, icier and more dangerous routes. Iconic mountains around the world are struggling with similar overcrowding and ever-drippier glaciers but, as the birthplace of modern mountaineering, Mont Blanc finds itself on an especially large number of bucket lists.

It wasn't until 1786 that anyone claimed to have 'conquered' Mont Blanc. In 1760, young, wealthy scientist Horace de Saussure, fresh from university and a thesis on the science of heat, was in the Chamonix Valley to collect plant specimens. While he was there, he offered a reward to anyone who could reach the summit. After two men finally made it to the top one evening in August 1786, de Saussure managed several trips himself, establishing a scientific tradition of research in high altitudes. In the two and a half decades that passed, he'd become professor of philosophy at the Geneva Academy, making a name for himself with extensive studies of the botany, geology and physics of the Alps. As he developed his studies of the area, he also invented and improved many kinds of apparatus, including a 'cyanometer', for estimating the blueness of the sky; and a 'heliothennometer', a wooden box lined with blackened cork and covered with three sheets of glass, which he used to explore how solar radiation increased with altitude.

De Saussure's research would inspire future generations of called them 'damps', from the German word *dampf*, meaning vapour (as opposed to something soggy). There was 'chokedamp', a suffocating mix of nitrogen and carbon dioxide, or for any mix of gases that might explode, 'firedamp'. This latter group might be called 'stinkdamp' if you were lucky enough to be warned of its presence with a smell, or 'whitedamp' if you weren't. William Brownrigg, a physician and chemist living in the English coastal mining town of Whitehaven, became interested in the types of airs miners were breathing and how this might expand science's idea of gases. He collected bladders of firedamp for investigation at the Royal Society in 1730 and was elected a fellow in thanks. Local mining agent Carlisle Spedding had the bright idea of distributing this flammable firedamp throughout the town via underground pipes to use it to light the streets. The town refused, but Spedding used the method to light his own office and Brownrigg's lab. As we'll see in Chapter Three, it would be a while longer before gaslighting caught on. That lamp Volta had made to run on marsh gas was very much a scientific instrument – requiring specialist skills to work – and not a mass-market product.

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It wasn't long before Joseph Priestley was playing around with Black's discovery of carbon dioxide. A preacher, teacher, philosopher and writer as well as a chemist, Priestley couldn't help getting pulled into unpicking new ideas. A radical in both his politics and his science, the two often intermingled. His major work on gases, *Experiments and Observations on Different Kinds of Air*, warned that there could be philosophical and social, not just scientific, ramifications of such research, and that the English hierarchy might have reason to 'tremble even at an air pump or an electrical machine'. Science arrived in Priestley's life already wrapped up in politics. Born into a family of religious dissenters, he was excluded from mainstream English education and so had to challenge political orthodoxy simply to do scientific work. He'd studied at a dissenters' academy in Daventry and, after a stint as an assistant pastor in Suffolk that everyone agreed was a disaster, found a living teaching in Nantwich. As his students were, like him, excluded from Oxford and Cambridge, Priestley felt there was no point working from the usual Classical curriculum designed to prepare for admission. Instead, he'd teach maths, science, English and history, and not just limited to the Greeks and Romans either. This was quite innovative for the time, as was the fact he taught girls as well as boys, albeit in different rooms. Word soon spread, Priestley's reputation grew and in 1761 he was offered a post at the dissenters' academy in Warrington; and after his educational materials were published in 1765, he was awarded an honorary doctorate from Edinburgh.

The Warrington job gave Priestley the chance to learn practical lab skills. He'd help the chemistry lecturer produce nitric acid for his classes, bewitched by the ways in which careful heating and distillation could pull all sorts of coloured fumes and crystals from something as mundane as clay. In 1767, he moved back to Yorkshire and took up a post as a minister in Leeds, and it was there that he started researching airs in earnest. The home his family were due to live in was being refurbished, so they were offered temporary accommodation next to a brewery. Priestley was delighted at the prospect of vats of fermenting liquids just next door emitting a steady supply of Black's 'fixed air' and soon got experimenting, eagerly recruiting the slightly bemused brewery workers to help.

Playing around at the Leeds brewery, Priestley soon found that woodsmoke caught up in this fixed air would swirl and cascade over the sides of the vat, as it was heavier than common air. He also experimented on small animals and realised that although fixed air wasn't poisonous it wasn't exactly good to breathe either. Butterflies became sluggish when enclosed in a vial of fixed air, but they could be revived. The same was true for a frog and mouse, although he killed a snail. Trying similar experiments with plants, he started to unravel respiration. We animals breathe out 'fixed air', but plants breathe it in and then give us back the air we need. For Priestley, the science of respiration was wrapped up in his theology. He saw air as 'injured' by our breath and green plants carefully provided by a God who would not allow mankind to be suffocated by its continual exhalation (we can only imagine what he would have made of humanity's later exhausts, air pollution and the climate crisis). Another of Priestley's discoveries was that if he poured water back and forth over the brewers' vats he could suffuse it with the fixed air, providing a pleasant fizz. Keen to share this new discovery, he wrote up instructions for making this fizzing water and sold copies for a shilling each. News spread around Europe of this delightful discovery, for which Priestley won the Royal Society's Copley Medal in 1772, and various entrepreneurs developed devices for mass production – including Jacob Schweppe, who soon cornered the London market with his force pump. There was already a market for naturally sparkling waters from spa towns and people thought these lab-made fizzy drinks might have medical benefits. Priestley hoped it might be a useful treatment for scurvy and lobbied the navy sufficiently that Captain Cook took soda water machines on his 1772 voyage to the Antarctic. Over in the

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