More and More and More

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An All-Consuming History of Energy

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To Michel and Josette, Cecilia, Leonor and Esteban

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Preface

This book was born out of an unease felt when reading general histories of energy. At a time when coal consumption has just experienced major growth on most continents, academic works, representing the state of the art on the subject, are *still* telling stories of transitions between energy systems. The main arguments in this book matured in the intellectual atmosphere created by David Edgerton at the Centre for the History of Science, Technology and Medicine at Imperial College London, where I began my career in 2011. His *The Shock of the Old* is a major book that redefines the field of the history of technology, broadening its scope and interest; a book whose lessons for the climate issue had yet to be learned. Finally, the writing of this book was made possible by the time and intellectual freedom offered by the Centre National de la Recherche Scientifique and the École des Hautes Études en Sciences Sociales in Paris, and I would like to thank all their staff.

Thanks also to the many colleagues who, in one way or another, encouraged me to pursue the argument of energy symbioses: David Edgerton, Christophe Bonneuil and Charles-François Mathis who discussed, commented on and enriched previous version of this text, and also Dominique Pestre, Sabine Barles, Simon Schaffer, Soraya Boudia, Romain Huret, Franck Aggeri, Stefan Aykut, Harry Bernas and Béatrice Cointe, together with Christophe Cassen, Amy Dahan, Michel Damian, Jawad Daheur, Giuliano Garavini, Frédéric Graber, Sebastian Grevesmühl, Elie Haddad, Ciaran Healy, François Jarrige, Jean Jouzel, Michel Lepetit, Thomas Le Roux, Fabien Locher, Sophie Lhuillier, Valérie Masson-Delmotte, Antoine Missemer, Raphaël Morera, William Oman, Thomas Piketty, Antonin Pottier, Daniela Russ, Vincent Spenlehauer, Alessandro Stanziani, Thomas Turnbull, Adam Tooze and Paul Warde. Many thanks to the editorial teams and anonymous reviewers of *Annales des Mines*, *Revue d'histoire moderne et contemporaine*, *Revue d'histoire du XIXe siècle*, *Histoire et mesure* and *Terrestres*: their feedback helped me to clarify the argument of this book. Thanks also to the team at Penguin, particularly Simon Winder, and to my copy editor Charlotte Ridings.

In recent years, I had the pleasure to teach energy history to students in Paris at the École des Ponts et Chaussées and the École des Hautes Études en Sciences Sociales. Special thanks to those who worked under my supervision on related subjects: Nelo Magalhães, Gaëtan Levillain, Sam Allier and Jules Calage.

Finally, I had a lot of interesting discussions with some of the people involved in the story I'm telling. In particular, I would like to thank Nebojsa Nakicenovic, Cesare Marchetti's assistant in the 1970s, who played an important role at the International Institute for Applied Systems Analysis (IIASA) and within Group III of the Intergovernmental Panel on Climate Change (IPCC), Jean-Charles Hourcade, with whom I had many discussions on the last chapter of this book, and Youba Sokona, the current vice-president of the IPCC, who encouraged me to explore the disturbing history of its third group.

I have presented the arguments of this book on numerous occasions and in a variety of settings, not only academic and scientific, but also associative, governmental and international. Each time I have been struck by the interest aroused by a discussion based on figures, without taboos or positions of principle. On all these occasions, I have never received any serious objection to the thesis of energy symbioses, which seems original only in the light of a very strange standard historiography. The point of this book is not to say that the transition between energy systems is impossible because it did not happen in the past. The point is rather to take a fresh look at history in order to identify the factors that lead to energy accumulation – symbiotic processes that are still with us and that are not about to disappear.

Introduction: A Symbiotic History of Energy

> It is possible that effects [of global warming] become significant before the middle of the next century. This time scale is similar to that required to redirect, if necessary, the operation of the world economy, including agriculture and the production of energy.
>
> (World Meteorological Organization, Declaration of the First World Climate Conference, Geneva, 1979, p. 2.)

This book tells a new story of energy, one that makes it possible to understand the radical oddity of the notion of *energy transition*. Instead of presenting the succession of energy systems over time, it explains why all primary energies have grown together and why they have accumulated *without* replacing each other. Instead of considering energies as separate entities in competition with each other, it reveals the history of their entanglement and interdependence. The stakes could not be higher, as these symbiotic relationships explain the permanence of primary energies right up to the present day and constitute major obstacles on the road to decarbonization.

This book also offers the first history of the 'energy transition', not as a historical and material phenomenon but as a futurology, a technological project and a way of understanding the dynamics of change. It explains why stage-theory reasoning has been applied to a field – energy and the material world – that did not lend itself to it at all. It recounts the strange trajectory of the energy transition, a heterodox and mercantile futurology – a mere industrial slogan – which, from the 1970s onwards, became the future of experts, governments and companies, including those that had no interest whatsoever in seeing it happen.

This book is certainly not a critique of renewable energies. It does, however, explain why the concept of energy transition is preventing us from thinking properly about climate change. For half a century now, this notion has produced more scientific confusion and political procrastination than anything else. Transition projects a past that does not exist onto an elusive future. To have any chance of forging a climate policy that is even remotely rigorous, it is essential to have a completely new understanding of the dynamics of energy and materials. That is the aim of this book.

In search of transitions

The notion of energy transition makes a radically strange future seem natural. Yet it is from history, a false history, that it draws its persuasive force and its appearance of plausibility. As if echoing the transitions of the past – from wood to coal, then from coal to oil – we should now, in the face of global warming, be making a third transition to nuclear power and/or renewable energies. The climate crisis demands that we continue the history of capitalism and innovation, even accelerate it, to hasten the advent of a carbon-free economy. Thanks to the transition theory, climate change calls for a change of technology, not a change of civilization. The history of energy, its chronological routines, its stagist narratives of the past – the age of wood, the age of coal, the age of oil, the organic economy and the mineral economy, the first and second industrial revolutions – has played a discreet but central ideological role in the creation of this comforting future.[1]

Let us start by stating the obvious. After two centuries of 'energy transitions', humanity has never burned so much oil and gas, so much coal and so much wood. Today, around 2 billion cubic metres of wood are felled each year to be burned, three times more than a century ago.[2] Wood currently provides twice as much energy as nuclear fission, twice as much as hydroelectricity, and twice as much as solar and wind power combined (2019 figures).[3] Wood remains an essential source of heat for the poorest third of the world's population – 2.3 billion people – who are also the first victims of pollution. But rich countries have also seen their consumption of wood energy increase: the United States burns twice as much as it did in 1960, and Europe three times as much as it did at the beginning of the twentieth century.[4] However, historians have been most interested in wood when it seems to disappear: its alleged ousting from the English energy mix in the nineteenth century has been the cause of more spilled ink than its rise throughout the world since 1950.

The same bias applies to coal: historians have mainly written about the situation in Europe in the nineteenth century, even though this is neither the main place nor moment in coal's history. The overwhelming majority (95 per cent) of coal was mined after 1900, and most of it was mined outside Europe (86 per cent).[5] Medium-sized Asian powers such as Australia and Indonesia currently extract twice as much coal as the giants of the 1900s such as Britain and the United States. In many ways, coal is a new energy. The strongest growth in its history occurred between 1980 and 2010 (+300 per cent), leading to an increase in its share of the global energy mix, to the detriment of oil. It was also in the 2010s that the number of miners reached its peak.[6] Lastly, coal-fired power stations are on average younger (around fifteen years old) than atomic power stations (thirty-two years), and are often much more efficient.[7] Coal was the great energy of the 2000s: it fuelled the internet revolution, which is basically just another electron network, just as much as the industrial revolution.

While China plays a central role – each year it burns fifteen times more coal than England at its peak and more than France throughout its history – this country is exceptional only in terms of its size. Since 1980, coal consumption has increased tenfold in China, but it has multiplied by 12 in Taiwan, by 11 in Vietnam, by 10 in the Philippines, by 8 in India, by 7 in Turkey, by 6 in South Korea and by 50 in

Indonesia. India, South Africa and Poland all have electricity mixes that are more coal-intensive than China's. And coal is not just the energy of development. Between 1980 and 2010, coal consumption doubled in the United States, Japan and the Gulf States, before falling back, mainly because of the rise of natural gas. Bush's America consumed four times as much coal as Roosevelt's.

That leaves us with Europe. The first to enter the 'coal age', Europe is also, we are told, the first to escape from it. This European exception, like so many others, needs to be put into perspective. The decline in coal use that began in the 1960s looks like a long, slow and cautious retreat. In 2020, Europe still consumes 400 million tonnes of coal a year, and the continent's major industrial power, Germany, remains one of the world's leading producers of lignite, the most polluting of fuels. Angela Merkel's Germany consumed three times as much coal per year as Bismarck's Germany. What is less well known is that Europe is also a world leader in manufacturing mining equipment, and it is partly thanks to European machines that world coal production soared in the twenty-first century.[8] Last but not least, the European Union, like all rich countries, engages in large amounts of foreign trade, and more than a quarter of the manufactured goods it imports are based on coal energy. However 'green' their energy systems may be or become, the rich countries, for the simple reason that they are rich, are resolutely on the side of the big coal consumers.

If we take into account the coal incorporated into imports, the UK would consume around 50 million tonnes – instead of the 9 million officially burned.[9] One study even puts that figure at 90 million tonnes – almost as much as on the eve of Margaret Thatcher's assault on the country's mines. Similarly, France consumes not 6 million tonnes of coal a year but rather 70 million, a quantity close to its peak extraction in the 1960s.[10] Whatever the accuracy of these figures, the important point is that in a globalized world, the decarbonization of a national economy is a difficult phenomenon to measure and that the 'transition' of the rich countries of Western Europe away from coal is, in part, a statistical artefact linked to a convenient convention: the attribution of CO_2 emissions to the countries producing the goods and not to the consumers.

Other imputation criteria would produce different results.[11] Let's take the case of Switzerland. This prosperous country has never been a major coal consumer, and its last mines closed in 1945. But it should be noted that its prosperity is partly due to the fact that Switzerland is part of a global economy that still consumes a lot of coal. For too-well-known reasons, international mining companies such as Glencore have their headquarters in Switzerland. They control the extraction of at least half a billion tonnes of coal per year. What's more, 40 per cent of the international coal trade is conducted in Switzerland, with Trafigura being a key player in this field. In total, at least a billion tonnes of coal contribute directly to the prosperity of the Swiss Confederation, which is quite a lot for a country of 8 million inhabitants.[12] Other similar examples include Luxembourg, home to ArcelorMittal, the world's leading steel company, or Norway, with its luxury electric cars bought with oil revenues.

The epic of energy transitions

Despite its fundamental dynamic of accumulation, the history of energy is generally told as a series of transitions or shifts in energy systems, on the scale of nations, continents or even the world as a whole. In what has become a genre in itself – the epic of energy transitions – we generally find the same chronological structure: initial chapters deal with muscle power, wood and water power in the pre-industrial era; central chapters deal with coal and steam in the nineteenth century; this is followed by chapters on oil, electricity and nuclear power (gas is often less studied); and finally, concluding remarks on the transition to 'green' energy in progress or to come. As each era is defined by the new – a bias common to the history of technology, rightly highlighted by the historian David Edgerton – massive phenomena are erased, such as the rise of renewables in the nineteenth century, biomass and muscle power in the twentieth century, and the recent rise of coal.[13] 'King coal reigned for about seventy-five years, before ceding the throne to oil in about 1965' wrote a leading figure in American environmental history recently.[14] The transitionist model is so deeply rooted that even a book of reference such as *Power to the People* contains some questionable assertions. For example, oil and electricity are presented as two 'energy transitions', whereas electricity increases coal consumption and oil does not necessarily reduce it.[15] The case of Vaclav Smil is also revealing. A leading expert on energy issues, he is currently one of the most influential voices warning of the enormity of the challenge represented by a global transition away from fossil fuels in thirty years' time. But his scepticism about the current transition does not prevent him from reiterating in his historical epics on energy the classic narrative of a modernity made up of transitions.[16]

Of course, there are other ways of telling the story of energy. Professional historians generally prefer to focus on a particular energy source. There is a wealth of literature on coal and oil, and other works on wood, hydroelectricity and, more recently, wind and solar power. The problem with these approaches is that they are 'mono-energetic'. They study one form of energy separately from others and from materials in general. However, we cannot understand much about the history of coal without studying the history of the wood used to extract it. Similarly, the rise of oil in the twentieth century is inexplicable without concrete, steel and, by extension, coal. This book aims to show the importance of a host of objects and techniques – mine props, railway sleepers, oil pipes, creosote, plywood panels, concrete mixers, dump trucks, cardboard boxes, wooden pallets, etc. – that are absent from standard accounts and yet are key to understanding the material history of energy.[17]

Since the 2010s, a number of historians have sought to renew the genre by challenging the primacy of economics, relative costs and resource availability in favour of the political determinants of 'energy transitions'. In *Fossil Capital*, for example, Andreas Malm explains the spread of the steam engine in England in the 1830s as a result of capitalists' desire to escape the locational constraints imposed by water power. Steam enabled them to move production to the cities to better exploit the abundant labour force that resided there.[18] In his famous book *Carbon Democracy* – to which we will return in Chapter 6 – Timothy Mitchell also offers a political account of the switch from coal to oil: the fluidity of oil is said to have enabled capitalists to circumvent the power and demands of European miners at the end of the nineteenth century.[19]

While the desire to inject politics into the somewhat smooth narratives of the economic history of energy is laudable, it should be stressed that these authors are repeating the standard transitionist story, and even exacerbating it by applying chronological periodization derived from the history of politics to the history of energy. As far as Malm's thesis is concerned, historians have shown that the steam engine of the 1830s was more a symbol than a trigger for 'fossil capital'. In nineteenth-century Britain, coal was burned primarily to produce domestic and industrial heat, and secondarily for steam and mechanical power. From the seventeenth century onwards, the demand for heating had led to a gradual increase in the price of firewood and a corresponding increase in coal mining. It should be added that steam did not replace hydraulic power. In fact, the use of water power in the British textile industry remained stable during the nineteenth century. Steam engines were used especially where rivers were overcrowded with watermills, like in Manchester.[20] Industrialists who were able to do so used both a water turbine *and* a steam engine. In France, for which precise administrative statistics are available, in 1860 half the companies using steam had another engine too, usually hydraulic, and steam engines were often used to pump water into the reservoirs when rivers were running low.[21] As for the hypothesis that capitalists had a particular appetite for urban crowds, it seems contradictory to the many projects to relocate industry to the countryside, synonymous with relative social calm. In the United States, in Massachusetts, textile capitalists had no difficulty in prospering thanks to hydraulic power, by completely transforming the River Merrimack.[22]

Timothy Mitchell's book comes up against the same stumbling block: oil does not bypass miners because, simply, it does not replace coal. Oil is used primarily to power cars, which in turn require a lot of coal to manufacture. Moreover, in the twentieth century, electricity gave coal a new economic centrality; the number of miners declined not because of oil but because of productivity gains in the mines. The attraction of the 'political' history of energy, which is also its flaw, is that it tends to present climate change as a capitalist conspiracy. This apparently radical but ultimately reassuring story underestimates the immensity of the climate challenge. Getting out of carbon will be far more difficult than getting out of capitalism, a condition that is probably necessary but certainly not sufficient.

A major criticism of transition epics has come from historians with a thorough knowledge of nineteenth-century modes of production, and consequently less impressed by coal and steam than their energy-specialist colleagues. They showed the importance for industrialization of energies that are wrongly regarded as traditional: whether human muscle, water power in factories, wood in the iron and steel industry, animals in transport, agricultural work or as industrial mechanical power.[23] But as a critique of transition, this history of technological persistence remains middle of the road.[24] The idea that traditional energies would 'resist' in the face of fossil fuels still takes the transitionist narrative too seriously. To understand the history of energy, we need to get rid of both Schumpeterian Darwinism – the too-simple idea of 'creative destruction' – and the dialectic of winners and losers. In the nineteenth and twentieth centuries, renewable energies did not put up barriers to fossil fuels, but progressed and developed thanks to them. As we shall see, coal and oil greatly increased the production of wood and its availability for energy purposes. Renewables improved thanks to steel and cement, two materials that are closely dependent on coal, enabling them to capture diffuse energies much more efficiently. In France, the steel turbines of the 1900s produced three times as much energy as the wooden mills of the 1800s, at a much lower cost, even before the rise of the large hydroelectric dams that were obviously dependent on oil

Wind turbines at the Chicago World's Fair in 1893. By the end of the nineteenth century, at least a million windmills were pumping water in the Great Plains of the Midwest. The development of wind turbines is inextricably linked to that of fossil fuels. Wind turbines have benefited from advances in metallurgy, sheet metal stamping, ball bearings, steel tube production and cement. Their lubrication system was inspired by that of car casings, and, between the wars, the blades took on their modern shape thanks to advances in aviation. Conversely, in the arid regions of Texas, wind turbines were used to supply water to locomotives burning coal.[25]

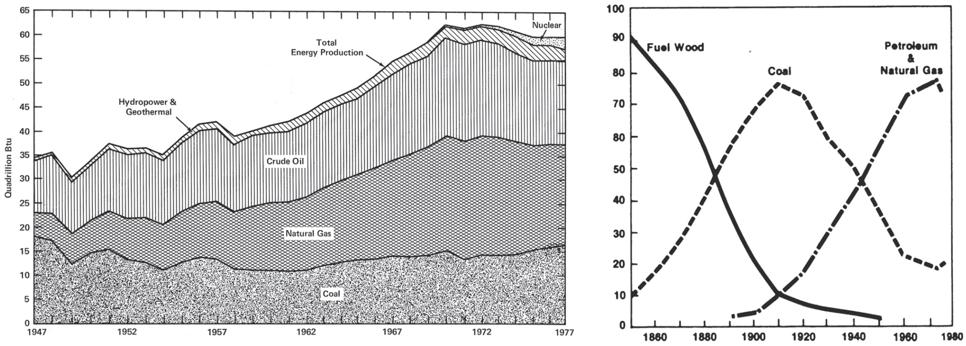
and coal for their construction.[26] Similarly, oil and gas have made it possible to increase agricultural production and hence the availability of human energy. For these and many other reasons, the story we tell in this book is not one of resistance, or even of additions, but of the entanglement and symbiotic expansion of all energies.[27]

When every tonne counts

There is no reason why historians should choose transition as the main motif of their accounts. Energy sources are as much symbiotic as they are in competition, and their symbiotic relationships explain why, over the course of the nineteenth and twentieth centuries, primary energy sources tended to add up rather than substitute each other. This observation leads to an obvious question: how is it that the idea of transition has become so widely accepted? Why did this future without a past became the future of governments and experts from the 1970s onwards? And how has it rubbed off on historians' accounts of the past? The last four chapters of this book will provide detailed answers to these questions. Let us simply mention for the moment that if the concept of transition poorly describes past transformations, it is because that was not its purpose: the idea comes not from an empirical observation of the past, but from anticipation of the future; it comes not from historians, but from futurologists. The history of energy was born out of futurology: it was to estimate future consumption that the first works on the quantitative history of energy were carried out. It is also in order to anticipate changes in the energy mix that certain experts, proponents of the atom, have considered energy dynamics not in absolute but in relative terms. From this matrix, historians have inherited certain ways of thinking about and representing energy. They have chosen to focus their analyses not on absolute values but on changes in relative shares, and they have adopted, without too much reflection, the lexicon of certain futurologists of the 1970s: expressions such as 'energy system' and 'energy transition'.

More often than not, historians have been content to characterize the transition in qualitative terms, as the shift from one 'technical system', to another, with all the economic, social, political and cultural consequences that this would entail. When we see the flagrant errors in the history of energy made by the French historian Bertrand Gille, who introduced the notion of *système technique*, we understand that this latter notion must be handled with care.[28] Its main problem is that by focusing on the 'coherences' linking techniques, materials and energies in each period, 'technical systems' have fostered a discontinuous vision of the history of energy, based on the dynamics of technological substitution.

The divergence between history in relative terms and history in



Two ways of representing the US energy mix: in absolute terms on the left, and in relative terms on the right. This second method appeared in the mid-1970s, first in the energy forecasting field and then in the US administration after the 1973 oil crisis. It was also at this time that a new body of expertise focused on transition was born. (Energy Information Administration, 'Annual Report to Congress', 1978, p. 2 and Executive Office of the President, *National Energy Plan, 1977* (Cambridge, MA, 1978).)

absolute terms is not just a matter of academic debate on the interpretation of modernity. It is also about the politics of history in the face of climate change. Since the 2000s, some experts have been searching for clues and fragments of answers in the history of energy to address the most pressing contemporary questions: how long could the transition take? How can we speed up the process? What is the role of the market? of the state? of innovation? Historians have willingly lent themselves to this game, and we have seen colleagues who specialize in the Industrial Revolution offering advice on transition, even though they have only ever studied energy additions.[29]

History – although not historians – also occupies a prominent place in an academic field that emerged in the 2000s: *transition studies*. The founding article, written by the sociologist Frank Geels, studied the spread of steam navigation in the nineteenth century in order to infer a theory of transition supposedly useful for decision-makers.[30] This article, which recycled Schumpeterian studies of innovation, was surprisingly successful. Currently, another author, Benjamin Sovacool, is working to spread a reassuring discourse: the long-awaited energy transition could happen much faster than those of the past, with 'evidence' such as the rapid deployment of a handful of technologies ranging from air conditioning in the United States to butane stoves in Indonesia, to natural gas in the Netherlands.[31] As with steam navigation, it is difficult to discern the link between the success of a few polluting technologies and the current challenge of decarbonization. The sleight of hand of transition studies is to equate transition with the diffusion of innovation and to reformulate the quantitative studies of innovation, common since the 1970s, in the lexicon of sociological theories. This prolific literature is fuelled by the ambiguity of the word 'transition' (technological? energetic? relative? absolute? deep? shallow?) and by endless discussions between approaches ('multi-level perspective', 'socio-technical transitions', 'large technical systems', 'social construction of technology', 'actor-network theory') that are theoretically different but really very close.[32] But this doesn't matter; because of their optimistic and constructive tone, well-funded by the European authorities and in vogue in business schools, transition studies have acquired a scientific weight out of all proportion to their empirical contribution. In its March 2022 report, Group III of the IPCC drew on this literature to make the strange assertion that 'energy transitions can occur faster than in the past', and that 'a low-carbon energy transition needs to occur faster than previous transitions'.[33] What is most worrying here is not so much the extent of the influence of transition studies as the fact that a stagist and false history of energy can thus pass all the validation procedures put in place by the IPCC.[34]

Faced with the climate crisis, we can no longer be satisfied with a history written in relative terms. A 'transition' towards renewables that would see fossil fuels diminish in relative terms but stagnate in terms of tonnes would solve nothing. We can no longer be satisfied with the vagueness of transition and its innumerable epithets, nor with the misleading analogies between the pseudo-transitions of the past and the one we need to make today. The climate imperative does not call for a new energy transition, but it does require us to voluntarily carry out an enormous energy amputation: to get rid, in four decades, of the proportion of the world's energy – more than three-quarters – derived from fossil fuels. To think that we can draw some useful analogies from history dramatically underestimates the novelty and scale of the climate challenge.

The history of energy recounted in this book is different from accounts that have gone before, in that it is concerned with absolute values rather than relative dynamics; it deals less with the replacement of engines and more with the persistence of materials; it does not separate the production of energy from that of materials; it does not recount the epic struggles between energy systems but the alliances and mutually supportive relationships that exist between them. We will see how energy sources are in a symbiotic relationship as much as a competitive one, and how these symbiotic relationships explain why, over the course of the nineteenth and twentieth centuries, primary energies have tended to add to rather than substitute each other. The 'transitionless' history that this book proposes does not mean that nothing changes – quite the contrary – but that change is better understood when we leave behind the stagist narratives of the material world.

As we have said, the history of energy is often called upon to 'illuminate' the present. The approach of this book is exactly the opposite: it is the contemporary challenges of transition that throw a harsh light on the gaping holes in our historical understanding of energy. The slowness, even the stagnation, of the much-desired transition necessarily renders the 'great transitions' of the past suspect. The material and energy imbroglios revealed by industrial ecology and life-cycle analyses point to fundamental entanglements that historians, overly concerned with periodization, systems, dynamics and modernity, have left in deep obscurity.

1.
A History of Energy by Candlelight

In 2018, the Nobel Prize in Economics was awarded to two Americans, William Nordhaus and Paul Romer, for their work on climate and innovation respectively. The message of economics to the rest of the world was unambiguous: it is through innovation, through the 'creative destruction' so dear to Joseph Schumpeter, that we can effectively combat global warming. At the awards ceremony, Paul Romer chose to illustrate this thesis with an edifying story about light. He referred to an article written twenty years earlier by 'his friend Bill' (Nordhaus), notable for measuring the collapse in the price of light from Roman oil lamps to contemporary light bulbs.[1] The fight against global warming, Romer explained, had to be part of this story of innovation, growing efficiency and increased well-being. From this vision of technological progress, economists drew an almost unique recommendation: the carbon tax, designed to put companies on the right track of 'green innovation'.[2] In addition to the tax stick, there is the carrot of subsidies to help companies break free from their 'path dependency', a path that would lead them down the fossil fuel-dead end. Instead of moping around, Romer concluded, all we need to do is point 'our innovative efforts in a slightly different direction'. And that '[decarbonizing the economy] will be so easy that looking back it will seem painless'.[3]

This rather surprising understatement is based on a widespread error that tends to confuse technology with innovation.[4] Since climate change is caused by second nature as a whole, by all the techniques and infrastructures accumulated in the world over the last two centuries, acting on the technological frontier, 'slightly modifying' the direction of corporate R&D as Romer suggests, will obviously change the quantity of CO_2 emissions only marginally and in the distant future. Innovation is preventing us from having an adult conversation about climate change. Even though it is constantly invoked in relation to the climate, innovation is, in reality, simply a way out, a procrastination tactic. Instead of wandering around dreaming about hydrogen-powered aircraft, nuclear fusion or the third industrial revolution, we should be basing climate policy on existing, available and cheap technologies, on the relevance of their use and on the fair and efficient distribution of CO_2 emissions.

Romer's understatement reflects a strange intellectual phenomenon: the extraordinary success of the simplistic idea of 'creative destruction'. It is striking to see the extent to which this shortcut has been taken seriously by countless experts and economists, including experts on 'energy transition'. Not only is this idea generally false from the point of view of the history of technology – the new does not make the old disappear – but as far as the climate and the environment are concerned, it is entirely and totally refuted by the history of materials. In fact, it was refuted even before Schumpeter formulated it.

As an American forester remarked in 1928, whatever the technological innovations – and he was thinking of cement-and-steel skyscrapers – 'raw materials are never obsolete'.[5] Work in ecological economics has confirmed this remarkable conjecture.[6] Any serious discussion of climate change should start from the somewhat worrying observation that technological innovations have never, right up to the present day, caused any flow of material consumption to disappear. Over the course of the twentieth century, the world's range of raw materials expanded, and each was consumed in increasing quantities.[7] Of the major raw materials, only the use of sheep's wool has fallen, because of the diffusion of synthetic fibres, which is not good news for the environment. The total weight of materials used by the economy has increased twelvefold, and after the year 2000 there was a further acceleration, far greater than the famous 'great acceleration' of the 1950s.[8] For the time being, therefore, substitution processes have always been trumped by the expansion of markets, by rebound effects and by the reorientation of raw materials to other uses.

This chapter takes the supposedly luminous example chosen by Romer to understand the climatic failure of technological futurism. Even in a field – artificial light – where progress and efficiency gains have been spectacular, in a field that has been turned upside down by a real technological revolution – namely electricity – 'creative destruction' has ultimately destroyed nothing in terms of material consumption. Quite the contrary.

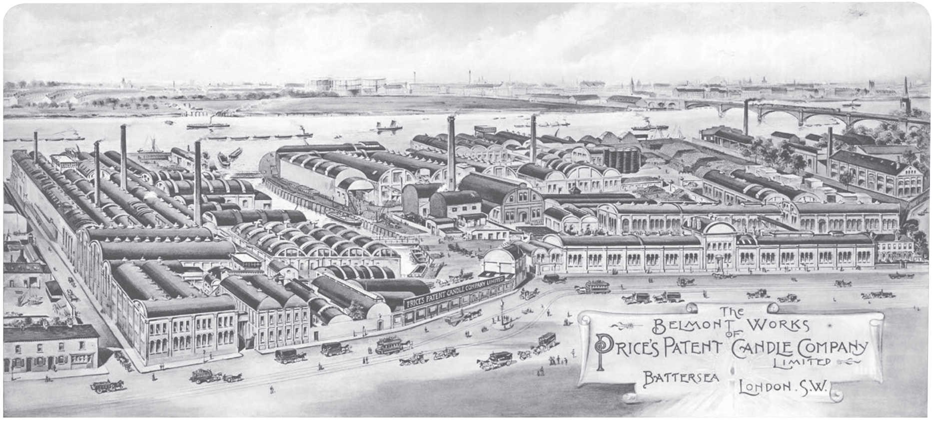
Modern candles

The material history of light is different from the history of lighting technologies and has nothing to do with the edifying history proposed by the new Schumpeters of the climate. In the picture painted by Nordhaus of the benefits of economic freedom guiding inventors, it is gas that is bizarrely presented as the essential breakthrough between 1820 and 1850, even though very few people were using it at the time.[9] 'There were virtually no new devices and scant improvements', writes Nordhaus, 'from the Babylonian age until the development of town gas in the late eighteenth century.'[10] Presenting gas as progress poses another problem. The process consisted of distilling coal in cast-iron vessels heated with coal. The gas obtained was stored in a gasometer before being distributed through a network of lead pipes. At the outlet of the gas burner, a mixture escaped that was mainly composed of hydrogen, which had little lighting power. Between the losses in heating the retorts and the leaks in the network, the efficiency of the process was disastrous.

In 1819, a chemist wisely pointed out that if the oil lamp had been invented after gas, everyone would have admired this simpler, less capital-intensive, less dangerous and more efficient innovation, which also used a renewable resource – seed oils. Until the end of the nineteenth century, history did not prove him wrong: the real advances in lighting in the 1800s were not in gas, but in lamps and candles. These techniques were just as 'modern' as gas and, in many respects, superior to it – their efficiency, as we shall see, was much higher. The stearic candle, which was invented *after* gas, is the result of advances in organic chemistry and the extraction of stearin, a fatty acid that remains solid at 60°C. Stearic candles are nothing like the tallow candles of the eighteenth century: they don't drip, smoke or smell.[11] From the 1830s onwards, candle factories sprang up all over the world, first in the major cities of Europe, then worldwide by the end of the nineteenth century.[12] From fuel to wick, the candle was a veritable cornucopia of innovations. Candle production, taking place both in small workshops and in gigantic factories, was mechanized with machines using compressed air to remove candles from their moulds.[13] The main economic interest of the candle industry is that it converted just about any organic fat – slaughterhouse waste, cooking residues, etc. – into a product with high added value.

Much more than gas, the candle was a global technology. Palm oil from West Africa was particularly sought after by candle manufacturers for its richness in stearin. Both French and British imports quadrupled between 1850 and 1900, with around half going to candle factories.[14] Great Britain, world leader in coal-gas consumption, also consumed a lot of palm oil – four times as much as France: gas and candles were clearly not mutually exclusive. To capture the greasy windfall from Africa, candle factories moved to the ports: the two leading candle companies of the nineteenth century – Price's Patent Candle Company in Liverpool and Fournier in Marseilles – exported candles to the four corners of the world. Great innovations were born from the candle: it was in a chemical laboratory working for the pioneering Parisian company L'Étoile that the Italian chemist Ascanio Sobrero synthesized nitroglycerine for the first time – he was looking for a use for glycerine, a residue from the extraction of stearin. Alfred Nobel, who was apprenticed to Sobrero at the time, benefited immensely from his colleague's discovery.[15]

Without going into too much detail, the oil lamp was also completely reinvented from the end of the eighteenth century onwards. Hollow cylindrical wicks and glass tubes increased the flow of oxygen



Candles are just as 'industrial' as gas and because they were much easier to transport than gas their production was far more concentrated. In France in the 1870s, there were around a hundred candle factories, including three very large ones, and almost five hundred gas factories. In England, Price's Patent Candle Company, based in London and Liverpool, dominated the market. It reached its peak at the beginning of the twentieth century: its Battersea site in London covered 5 hectares, employed 2,300 workers and produced 160,000 tonnes of candles a year using palm oil and petroleum wax.

and made the flame much brighter. The first people to see these new lamps were amazed.[16] The fuel – mainly rapeseed oil, with petroleum making its appearance in the 1860s – was purified more effectively using powerful acids. The regular feeding of the wick was improved by numerous inventions in the field of mechanics and sealing. A visitor to the 1834 Paris Industrial Exhibition noted that 'lamp-making has now become as difficult a science as algebra'.[17]

The materials behind the techniques

It's easy to see why gas didn't replace lamps or candles in the nineteenth century, but rather supplemented them in a modest way, its use concentrated in cities, and by the bourgeoisie, factories, theatres and shops. The transition from organic to mineral sources of lighting did not really start until the very end of the 1800s, with kerosene lamps and candles made from petroleum paraffin. But the important point is that this 'transition' in no way prevented increased consumption of the original materials concerned. After petroleum replaced organic oils, consumption of palm oil, rapeseed oil and even whale oil continued to rise. Between the two world wars, global palm-oil exports increased fivefold (from 100,000 to 500,000 tonnes) for lubricants, soaps, food and pharmaceuticals. At the end of the twentieth century, with the rise of 'biofuels', the energy use of vegetable fats increased tremendously. Nowadays, French cars alone burn between 300,000 and 500,000 tonnes of palm oil a year, about as much as the world consumed in the 1930s. French motorists also burn between 2 and 2.5 million tonnes of rapeseed oil, at least ten times more than all French candles and lamps in the mid-nineteenth century.[18] Similarly, once electricity had blown out the flame of gas burners, coal

Grand ball given by the whales in honour of the discovery of oil in Pennsylvania. (*Vanity Fair*, 20 April 1861.)

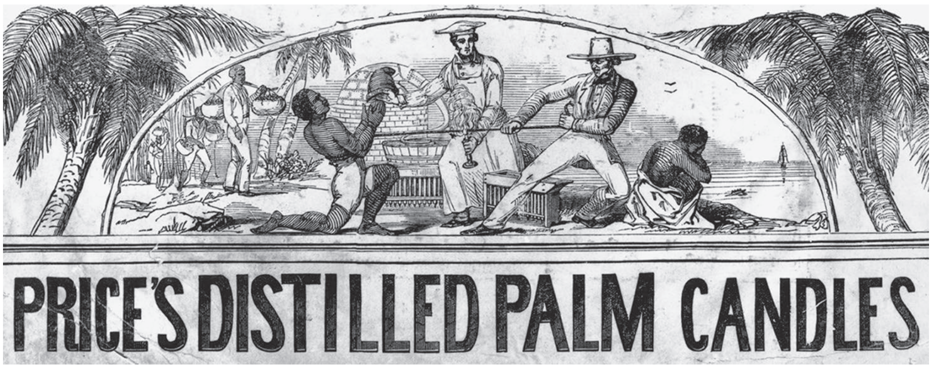
gas found many other uses for domestic heating and cooking, and coal has never been distilled as much as it is today, to produce coke for the steel industry, methanol and many other chemical products.

Then there is the case of whale oil, rightly famous as one of the rare historical examples of the disappearance of an energy source. But it is important to understand the significance of this exception. In his article, William Nordhaus does not hesitate to repeat an old cliché, dear to the hearts of American oilmen: oil saved the whales. Nordhaus even adds that the good fortune of these cetaceans was that, in the days of Edwin Drake and John D. Rockefeller, there were no environmentalists or impact studies to prevent the rise of the oil industry. There's no point in dwelling on this absurd argument, which has long since been refuted.[19] Let's just note that even before petroleum wax was introduced, there were several less expensive and far more abundant light fuels available than whale oil. Oil did not save the whales because innovations such as the stearic candle had already made spermaceti obsolete for lighting.[20] In England, according to the work of Roger Fouquet and Peter Pearson, at the beginning of the nineteenth century whale oil represented only 5 to 10 per cent of the light produced by candles.[21] In France, it was even less. At its peak, in the mid-1800s, six to eight ships brought back less than 2,000 tonnes of oil a year. Imports from the United States peaked in the 1840s at 5,000 tonnes, and then fell back below 1,000 tonnes for the rest of the century.[22] If whaling had been prohibited in 1850, an alternative would have been to increase rapeseed production by a few per cent, or to import slightly more palm oil.

In addition, the peak of the whaling industry was reached in 1960, a century after the advent of oil. In the twentieth century, during the so-called 'age of oil', three times as many sperm whales were killed (760,000) as in the nineteenth century (around 250,000).[23] Oil played a key role in this carnage: more powerful and more reliable boats powered with diesel engines chased whales to the furthest reaches of the southern hemisphere. Whale oil was no longer used as a source of light, but for many other purposes: margarine, pharmaceuticals, paint and explosives. Actually, petroleum *increased* the demand for whale oil: top-of-the-range lubricants for gearboxes and machine tools used to contain between 5 and 20 per cent whale oil. Until the mid-1970s, aircraft turbojet engines were lubricated at least in part with whale oil. In 1970, with the prospect of the end of whaling, companies began to stock up, and it was then that spermaceti oil reached the highest price in its history. If anyone wants to credit a substance with 'saving the whales', it is the jojoba, a tree native to Mexico whose fruit produces an oil very similar to spermaceti.[24] And this transition took place only because it was imposed on the industry by the ban on whaling that non-governmental organizations fought so hard to obtain. Contrary to what Nordhaus writes, it was environmentalists who saved the whales, at least those few that had survived the carnage of the twentieth century.

The labour behind the materials

The history of light illuminates a second important point for this book: the blurred nature of energies. The names we give them – 'oil', 'petroleum', 'gas' – are linguistic conveniences that obscure material processes that are much broader, more intertwined and more composite than we think. A stearic candle, for example, involved an enormous amount of human labour, mainly due to the extraction of palm oil. Depending on its quality, it took between 130 and 630 working days to produce one tonne of oil. With all the limitations inherent in this kind of calculation, it can be assumed that 1 calorie of human energy produced just 3 calories of palm oil.[25] The candle economy was based on very low labour costs and often on slave labour. It is no coincidence that African palm-oil exports began to rise after the abolition of the slave trade: European merchants, deprived of the triangular trade, saw in this commodity a new way of making the most of the labour force available in West Africa. The abolition of the slave trade did not mean the end of slavery, but rather its expansion in Africa itself. In the middle of the nineteenth century, a palm-oil merchant from Marseilles admitted that the stearic



Advertisement for Price's Patent Candle Company. The candle burns the rope of servitude. By offering a legal trade to African sovereigns, the stearic candle may have helped to dry up the sources of the slave trade, but palm oil was largely produced by slave labour. Price's Patent Candle Company directly employed 2,300 workers in Britain but the palm oil it used required tens of thousands of men and women in West Africa.

candle had certainly helped to dry up the slave trade, but only because the West African kings had an interest in keeping slaves on site to harvest and extract the oil.[26]

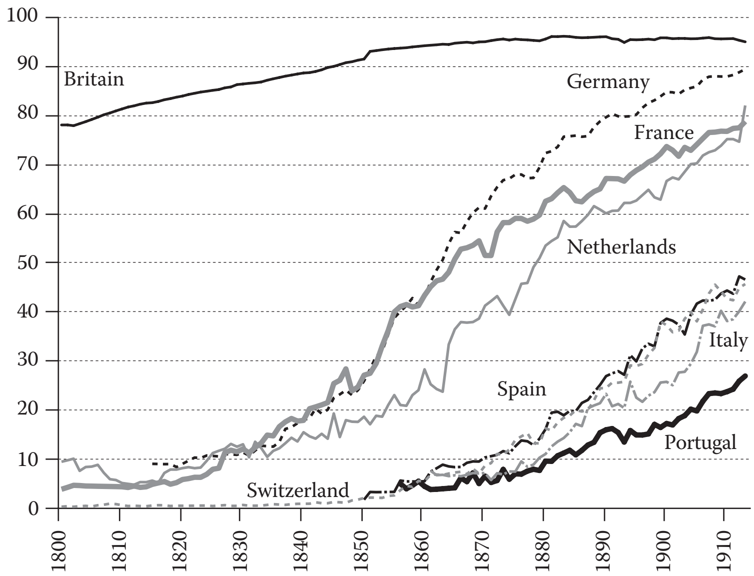
The European lights of the nineteenth century were therefore based partly on slavery in Africa, but also on many other workers, other materials and other sources of energy: on the toil of the peasants who grew rapeseed and poppy, on the mills that crushed oilseeds, on the millions of hectares of grassland in Europe and America used to fatten cattle.[27]

The emergence of fossil fuels adds a new level of complexity but does nothing to change the interweaving of materials and energies that lights up the world. Indeed, gas lighting was produced from coal extracted from mines, which in turn were significant consumers of lighting oil. In the 1860s, a miner extracted an average of 200 tonnes of coal a year with the help of 60 kilos of oil or candles. The gas itself therefore depended on a large quantity of organic light. The cost of lighting was considerable: less than the cost of labour and pit-props but more than capital remuneration.[28] Similarly, the petroleum that made European lamps shine at the end of the nineteenth century had a much broader material and energy base than the chemical energy it contained. Its extraction required wooden derricks, it was pumped by steam engines, it crossed the Atlantic in sailing ships, it was stored in wooden barrels that required coal and muscle power to make, and so on.[29] When we consider the materiality of their production, the words 'oil' or 'coal' become problematic. The candle sheds light on a point that is both trivial and rarely taken into account in thinking about energy and writing its history: energies are symbiotic entities, depending on complex webs of materials from which this book draws some threads.

The mismeasure of energy

The material history of illumination sheds light on a final, more historiographical point. In books on the history of energy, in particular Kander, Malamina and Warde's *Power to the People*, we can admire spectacular curves showing the early triumph of coal in industrial countries: by 1800, 80 per cent of British energy was derived from coal. In France and Germany, by the middle of the nineteenth century, more than half of all energy depended on coal. These curves have rehabilitated a coal-centric history of industrialization, a vision that a generation of economic historians had criticized.[30] Undoubtedly, coal had a major economic impact on industrial countries by the close of the nineteenth century. The problem is that the methods used to measure this impact have the effect of anticipating and exaggerating its consequences.

Let's take the case of lighting in France in 1872, an example which has the merit of providing all the necessary statistical information. With only 470 gasworks, gas lighting was unknown in the countryside. The Seine department, and Paris in particular, consumed half of the gas produced nationwide. However, there were only 92,000 subscribers in the capital out of a total population of 2 million.[31] Gas was therefore used mainly to light the streets and homes of the bourgeoisie. Even in Great Britain, where gas was cheaper, only a quarter of the population had domestic access to gas lighting by 1885.[32] In Europe, and even more on other continents, rural and poorer people used lamps and candles for lighting. Not much, admittedly: in 1872, every French person had on average an hour and a half of candlelight a day. Although gas provided little light, it did consume a lot of coal: around 1 million tonnes in France in 1872, i.e. four times the mass of fat consumed by oil lamps and candles. Given the disastrous inefficiency of gas, this million tonnes of coal produced as much light as 120,000 tonnes of oil and candles. In short, gas consumed twice as much energy as candles and oil lamps to produce half as much light.[33]



Share of coal in total energy consumption. In Astrid Kander, Paolo Malamina and Paul Warde, *Power to the People. Energy in Europe Over the Last Five Centuries* (Princeton, NJ, 2013), p. 137. This graph represents primary energy (the amount of energy contained in a tonne of coal, for example) and not the energy actually used by final consumers (the work produced by a steam engine burning a tonne of coal, for example). In doing so, it exaggerates the importance of coal in 19th-century economies.

As gas lighting vigorously stimulates coal consumption, the latter is duly measured by energy historians who, on the other hand, do not bother with vegetable oils and animal fats, arguing that they contribute very little in comparison with coal.[34] This is entirely true from the point of view of primary energy consumption, but completely false when we look at the energy services provided. This distortion is general: it is due to the difficulty of accounting for so-called traditional energies and the low efficiency of machines using coal. The case of the steam engine is similar to that of gas lighting. According to the efficiency parameters used by energy historians in their calculations, an industrialist who replaces his water mill with a steam engine of *equivalent power* multiplies his energy consumption by a factor of between 5 and 10.[35] Similar remarks could be made about transport or certain chemical processes. Taken together, these distortions lead to an underestimation of pre-industrial energy and give the impression of extraordinary abundance as soon as coal enters the scene.

Many gigajoules would have to be subtracted from the spectacular curves of energy history: the heat lost in steam boilers or in the retorts of gasworks, the coal used in mines to extract coal (8.8 per cent in 1922 in Great Britain[36]), the coal used by locomotives and steamships to transport it, etc.[37] The purpose of these few remarks is not to say that the quantitative history of energy is false, or that economic growth could have continued unchanged without coal until the end of the nineteenth century (a counterfactual that has resulted in a lot of spilled ink in economic history[38]), but to show that it tells a particular story – that of primary energy consumption in a national territory – which is not the same thing as the energy services actually provided. Instead of restoring 'King Coal' to the throne of the industrial revolution, such a story would probably echo the findings of the cliometricians of the 1970s and 1980s on the progressive nature of economic growth. It would also show, alongside steam engines and gasworks, the role of candles, wheelbarrows, ball bearings, cranks, winches, lubricants, barrels, dollies, trolleys, bicycles, pedals, sewing machines, etc. – machines that consumed little energy but played a fundamental role in the economic growth of the nineteenth and twentieth centuries.

To conclude, let's return to the amphitheatre of the Royal Swedish Academy on 8 December 2018. In his speech, Paul Romer highlighted a little-known but important innovation, the Welsbach mantle, which at the end of the 1800s had increased the luminous power of gas tenfold. Welsbach, the inventor of the mantle, had made the lights of the industrial world shine brighter by covering the gas nozzles with a mesh of metal oxides.[39] The next slide of Romer's presentation illustrated the progress of lighting. Instead of the usual evocations of Times Square or Shibuya at night, it showed an anonymous street, probably that of a town in Africa: under the pale light of the street lamps, teenagers were revising with their textbooks. From light would come other lights, Romer explained, and, who knows, maybe one of these students, embarking on a scientific career, would discover the incandescent gas mantle of the twenty-first century, thus helping to solve the climate crisis.

Once again, the example was poorly chosen. The gas mantle, with its classic rebound effect, had considerably *increased* gas consumption and therefore CO_2 emissions. In 1900, Paris consumed more gas than the whole of France twenty-five years earlier. If we continue the story, it's true that electricity blows the wick out of kerosene lamps in rich countries, but it also leads to a huge increase in petroleum consumption for lighting. In 1973, a quarter of the world's electricity was produced from oil, and around a fifth of this electricity was used for lighting. Subsequently, oil's share in electricity production declined. But in the 2000s, the electricity used by car headlights alone consumed more than a million barrels of oil a day, twice the world production in 1900, to which must be added the 1.3 million barrels (in 2005) used to fuel lamps in poor countries.[40] Since 2000, on a global scale, despite the rapid spread of LEDs (which accounted for half of all lighting in 2020), electricity consumption for illumination has remained stable. Our light bulbs, however efficient, send almost a billion tonnes of CO_2 per year into the atmosphere, thousands of times more than in the days of gas lighting and kerosene lamps.[41] Finally, it is unlikely that some student in Africa or elsewhere will invent the equivalent of the gas mantle: LED lamps are already so efficient that progress in this domain is largely behind us.

The 2018 Nobel Prize award illustrates the obsolescence of Schumpeterian economists' modernist ideology: their answers no longer correspond to the question being asked. The two laureates learned their academic trade in the debates on growth initiated by the Club of Rome report and the energy crises of the 1970s.[42] In response to the warnings about the depletion of resources, they argued, partly correctly, that higher prices would encourage substitution between raw materials and innovation. According to the cake metaphor that economists relish, growth could continue endlessly thanks to new recipes (innovations) while consuming fewer and fewer ingredients (natural resources). Almost forty years later, our two climate Schumpeterians were rehashing the conventional refutation of Malthusian thinking about resources. The problem is that the climate crisis has nothing to do with this easy target. It is not a problem of gradual scarcity to which price rises, substitution and innovation could provide a response. It is not a question of whether there will be enough cake, but rather of what happens to the cake, however big and delicious it may be, after it has been eaten. Global warming is a tragedy of abundance rather than scarcity, a tragedy made all the more intractable and unjust by the fact that its victims are generally not responsible for it. Combating global warming means achieving an unprecedented transformation of the material world by sheer force of will, and in an extraordinarily short space of time. To claim that 'innovation' – be it incremental, granular, green, frugal or disruptive – is up to this unprecedented challenge is just smoke and mirrors.

2.

'The Age of . . .': Material Stagism and Its Problems

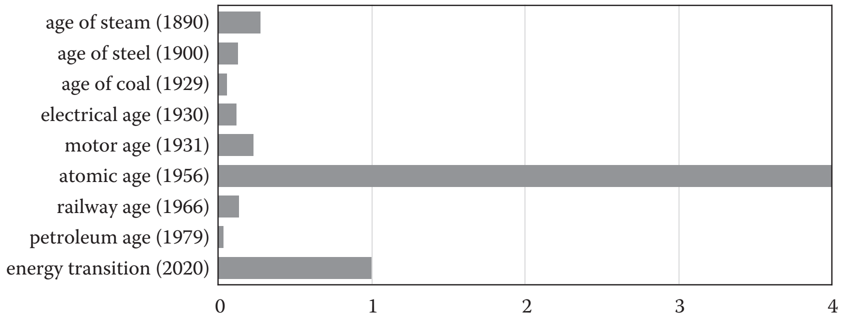
In the second half of the nineteenth century, an expression flourished in Anglo-American literature: *the age of*. In particular, it took over the titles of the technical journals founded at the time: *The Railway Age* (1856), *The Age of Steel* (1857), *The Iron Age* (1867), *The Gas Age* (1884), *The Petroleum Age* (1887), *The Electrical Age* (1897), *The Motor Age* (1898), *The Cement Age* (1904) and *The Coal Age* (1911). By vying with each other for the name of their era, these magazines testify, in spite of themselves, that industrialization was the sum and symbiosis of all these techniques and all these materials – and a thousand more besides. But taken one by one, they claimed to distinguish their era by a particular technique or material.

These titles reflect the rise of a new kind of stage theory: reading history as a succession of distinct material epochs.[1] This was a novel historical sentiment. In the previous century, the idea of living in the 'age of wood' or the 'age of the horse' or any other material would hardly have made sense. At the beginning of the nineteenth century, new ages did begin to appear, inspired by the 'golden', 'silver' and 'iron' ages of Hesiod and Ovid, but in a Romantic vein to deplore the triumph of materialism.[2] The difference, in the second half of the nineteenth century, is that these tropes were increasingly being taken seriously. But why? Who disseminates material stagism? What accounts for the success of the 'ages of'? And what are the historiographical consequences?

The seductions of material stagism

The problem is not periodizations in general, some of which are perfectly legitimate, but this empirically unfounded way of singling out certain materials, energies or innovations (and always the same ones) as defining their era. Take, for example, the idea of an 'age of coal' that is often used to characterize the nineteenth century.

In Britain, it is true that this material became a ubiquitous part of daily life. Between 1830 and 1900 its consumption increased tenfold.[3] The problem is that the use of many other materials also grew during the same decades: wood consumption increased by a factor of 6 and bricks by a factor of 5 – two materials which, as much as coal, marked the English landscape in the nineteenth century.[4] What's more, while in Britain the real progress of coal preceded talk of its age, in all other countries the opposite was true. In the mid-1800s, French mining engineers claimed that coal had become 'the backbone of the modern world',[5] 'the food' of the nation and even that 'industry lives only by it'.[6] According to the coal-mine owners, without them 'there would be no more industry, no more trade, no more power' as coal was 'force, movement and light',[7] even though its role in mechanical power and for lighting was still modest at the time. In any case, a 'realistic' interpretation of the *ages of* would not work for other materials. Oil never acquired the importance that coal had. Between the wars, when the 'motor age' was in full swing – in the press more than on the roads – the mass of oil consumed weighed less globally than milk or potatoes, and four times less than wood or coal.[8] In the 1920s, economists calculated that the value of world oil production was equivalent to that of horses and mules, and barely a quarter of that of rice or a third of that of wheat.[9] Finally, the 'atomic age' enjoyed extraordinary lexical success and marginal economic importance. One of the reasons why the history of energy has been so badly told is that it has tended to take this kind of trope seriously, to focus on a limited number of



Material ages endure, in fact and in the language. These expressions tend to reinforce themselves over time because they function by opposition. Never were so many people talking about the steam age as in the early days of electricity and oil: it was a way for new entrants to mark a break with the past while at the same time inscribing themselves in an august lineage. Similarly, the 'railway age' flourished in the 1960s, at precisely the time when train lines were being sacrificed to the car. The graph shows the frequency of 'age of X' at the time of its peak use (date in brackets) compared with the frequency of the expression 'energy transition' in 2020. For example, 'atomic age' was four times more common in 1956 than 'energy transition' in 2020. (Google Ngram English-language corpus between 1800 and 2020.)

techniques considered to be absolutely fundamental and to confuse the beginning of their use with their mass take-up.[10]

As the titles of the magazines mentioned above remind us, these formulas are nothing more than commercial slogans. It is hardly surprising, in itself, that oil companies should extol the age of oil, or gas sellers the age of gas. What is more surprising, and needs to be explained, is the infatuation of intellectuals with these promotional tropes.[11]

This way of thinking about matter and time was first given a certain prestige by two disciplines that revolutionized our understanding of the distant past through the use of material markers: geology and prehistory. The expression 'Coal Age' first referred to a geological period – the Carboniferous – before being applied to the nineteenth century. In England, an intense ideological relationship was established between these two periods: it was not historical contingency but Providence that, by stockpiling thick layers of coal in the ground, had ensured power and empire for the Victorians. By the 1830s, prehistorians, following in the footsteps of Christian Thomsen (the director of the National Museum of Denmark in Copenhagen), had constructed a stage theory of the distant past based on three materials: stone, bronze and iron – the Stone Age, the Bronze Age and the Iron Age.[12] In popular technology literature, the three-age system was sometimes presented as an introduction for the arrival of coal.[13] Krupps, Bessemer and Carnegie became the heroes of 'an age of steel' following the mythical ages of bronze and iron.[14] The three-age system made it possible to associate this or that innovation with the majestic course of human history, and this was precisely the effect sought by the high-sounding titles of the magazines mentioned above.

Secondly, the 'age of' notion corresponded well to a bourgeois interpretation of history. Marx, in his time, had already highlighted the fascination of economists with steam. He insisted on the primordial role of *machines*, which in textile factories had preceded the introduction of steam by several decades. The energy that powered them could vary: water, animals (including humans), or steam, and the three were not mutually exclusive.[15] In contrast, the technological literature of the 1860s depicted the steam engine as the essential breakthrough, connecting matter with genius. It is no coincidence that the 'age of coal' was also the age of the glorification of inventors, with James Watt dominating their pantheon. Louis Figuier, the famous French science popularizer, presented modernity as the result of human ingenuity. In his encyclopaedic history of technology, it is the scientists who unleash the forces of nature, almost in spite of the workers. The latter are strangely relegated to the side of inertia and resistance, even though they were clearly the most essential contributors to progress: no steam without miners, no railways without navvies.[16]

In the 1920s, the energy statistics that were beginning to appear were even more oblivious to human muscle. With the rise of oil and then hydroelectricity, statisticians were no longer content to count tonnes of coal and barrels of oil separately, but opted for energy units that aggregated all sources of heat, electricity and power.[17] Thanks to the ambiguity of the word 'work' the statistics justify some quite extraordinary assertions, such as one engineer explaining that 'in the United States two-thirds of the work is done by coal and most of the last third by gas and oil'.[18] On the basis of available power per capita statistics, the Americans, farmers and workers included, were depicted as oriental princes: 'each American is endowed with 40 invisible and obedient genies', and each worker was even said to have '3,000 energy slaves' at his disposal, according to Bassett Jones, the great elevator specialist of Manhattan in the 1930s, who was also one of the first to use this term which promised such a brilliant future.[19]

Thirdly, material phasism also corresponded to a certain futurology, that of the dread of running out of resources. Materials are seen as ages, when considered from the future as closed episodes. Stanley Jevons played a fundamental role here. His book *The Coal Question* (1867) launched a genre in its own right, that of energy forecasting.[20] But it is also a perfect example of material stage theory and mono-materialism. Coal, he writes, is the 'alpha and omega' of industrialization, trade and power.[21] Other materials receive only cursory treatment; the few passages devoted to wood deal with its scarcity in seventeenth- and eighteenth-century England. The general pattern is one of substitution: wood by coal, then coal by . . . nothing at all.[22] And this, despite the fact that Jevons could have extended his theory of the rebound effect to the English consumption of many other materials. Written in just three months and based on the strange hypothesis of a continuous exponential growth, *The Coal Question* launched a fifty-year debate on the exhaustion of coal and a wave of speculation on the material age that might follow. In French, one of the first occurrences of the expression *âge du charbon* is found in a review of Jevons's work: '*à l'âge du bois a succédé l'âge du charbon, à l'âge du charbon succédera l'âge d'une autre puissance*'.[23]

Who will the electric age belong to?

Around 1900, the identity of this mysterious *autre puissance* fascinated the public, in part because it seemed to be intertwined with the political fate of industrialized countries. What would be the consequences of electricity in the struggle between capitalism and socialism? In numerous futuristic texts from that era, coal, viewed as both environmentally harmful and socially problematic, was predicted to become obsolete. Electricity would reign supreme – even if it was not clear how it would be produced.[24] The social question underpinned these discussions: for capitalists, the end of coal could also mean the end of the challenges posed by the labour movement. The French chemist and minister Marcelin Berthelot predicted that by the year 2000, renewable energies would have rid the world of 'coal mines and consequently miners' strikes'.[25] With the development of hydroelectricity, some entrepreneurs hoped that a new wave of industrialization in rural areas would enable them to escape the cities contaminated by socialist ideas. This was one reason why in the 1920s Henry Ford decided to relocate part of his business from Detroit to some twenty villages in Michigan powered by hydroelectric dams.[26]

But socialists, too – and Engels was one of the first – were convinced that electricity would work to their advantage.[27] In a remarkable book published in 1910, *Fields, Factories, and Workshops*, Peter Kropotkin showed that small-scale manufacturing was still dominant in most industrial countries: electric motors, simpler and more affordable than steam engines, would modernize these countless workshops, making mass production and large factories obsolete. Thanks to electrification, production could continue in the countryside, reconciling agricultural and industrial work and thus strengthening workers' autonomy.[28] The German socialist August Bebel, returning from the 1900 Paris Exposition, was convinced that electricity held the promise of liberating women from domestic chores.[29] Innovation, however tenuous or, frankly, speculative ('vegetable electricity', to which

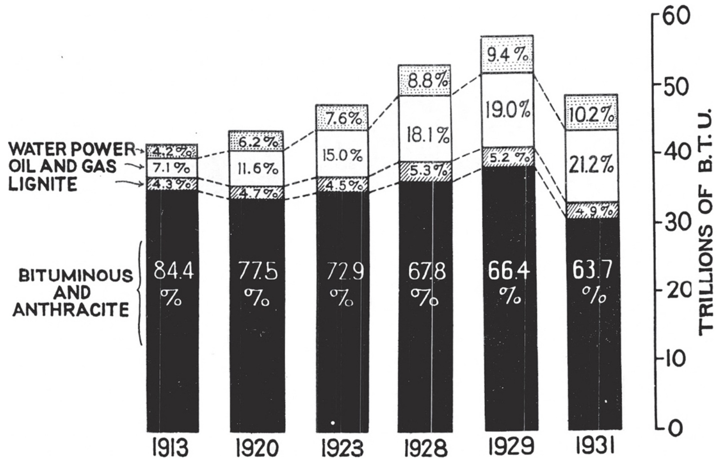
Bebel and Kropotkin devoted long pages), became emblematic of a world on the cusp of a profound transformation. Other socialists, like the English Fabians of the 1900s, insisted on the centralizing effect of the electricity network, which would make competition obsolete and impose economic co-operation. The monopolistic tendencies at work, 'gas-and-water-socialism', the placing of gas, electric and water companies under municipal control, seemed to indicate that capitalism had reached its limits in the face of technological development. Socialism became the condition for the electric age to fully blossom. For the Fabians, the key word for this transformation was 'transition', which they contrasted with the 'revolution' that had already taken place in the world of production.[30] The transition to socialism was an adaptation to the revolutionary changes in technology. In *Transition: A Novel* (1895), the novelist Emma Brooke portrays her heroine's choice between two lovers: an attractive foreign anarchist and a dull but solid English socialist reformer modelled on Sidney Webb, the figurehead of the Fabian movement.[31]

In 1925, the sociologist Patrick Geddes also used the word 'transition' in a lecture he gave to the Royal Society. England was going through a 'coal crisis'. The coal industry, penalized by the country's return to the gold standard and faced with competition from the mines on the Ruhr, was deprived of export markets. With miners refusing wage cuts, the mining companies decided to stop operations. A general solidarity strike was organized in May 1926. According to Geddes, this crisis was not the consequence of an inept monetary policy, but the sign of a Britain stuck in the 'coal age' (characterized, with irony, as a form of Stone Age), while the continent, 'from Finland to Palestine', was in the process of switching to hydroelectricity. Clean and inexhaustible, this energy promised to revolutionize Europe, beginning with its peripheries – the Alps, the Pyrenees and Scandinavia. There, along the rivers, in the countryside, virtuous people would cultivate 'the highest technologies'. According to Geddes, hydroelectricity would become the great redeemer of modernity: it would reconcile industrialization, the environment and eugenics, and would help to regenerate the soil and nature through the production of nitrogen fertilizers.[32] The transition was a matter of racial survival, and the English risked suffering the same fate they had inflicted on primitive peoples if they missed the 'neotechnical' transformation.

A 'common bugaboo'

By the time Geddes announced an imminent 'neotechnical' transition away from coal, economists, oilmen, geologists, foresters and even anyone consulting statistics knew that this hope was illusory. They knew that the nineteenth century had been the age of wood as much as the age of coal, and they predicted that the twentieth century, heralded as the age of oil and electricity, would burn ever more coal and use ever more wood.[33] They considered the idea of substitution to be simplistic and insisted, quite rightly, that the consumption of most raw materials was almost always increasing. The specialists made no secret of their annoyance at the propaganda of industrialists – and the intellectuals who followed them – about the 'age of oil' or the 'age of electricity', abrogating the deleterious reign of coal. One of them described the idea of substitution as 'common bugaboo'[34]: when a material is no longer used in a sector, its producers find other uses for it. Wood provided the most striking example of this maxim. Instead of its use being eliminated by coal and industrialization, wood was consumed more and more for construction, railways, mine timbering, crates, barrels, cardboard, paper, newspapers, hygiene products and so on. Egon Glesinger, the great specialist in forestry statistics between the wars, emphasized the enormous weight of wood used in the world economy (1.2 gigatonnes) compared with oil (0.27 Gt). Only coal was consumed in greater quantities (1.3 Gt).[35] Conservationists were far more concerned about the depletion of forests than about the depletion of coal, whose global reserves had been evaluated by geologists at 6,000 years of consumption at the 1913 rate.[36]

The same applies to the substitution of oil for coal. Oil, whose limited reserves are always stressed, is described by the experts as simply 'accelerating the progress' of an industrial world still based on coal.[37] Robert Brunschwig, a mining engineer at the French Office Nationale des Combustibles Liquides, described the 'end of coal' or the 'age of oil' as 'a brilliant and misleading oversimplification'. Although coal's relative share in the world's energy mix was declining because of the rise of oil, it remained by far the dominant energy source. Even though oil was overtaking coal in navigation and heating, experts believed that for a long time to come coal would remain 'the chief energizer of modern industry',[38] or 'the basis of the world of machines'.[39] The hope of a transition to



The first graphs representing the dynamics of energy systems appeared at the end of the 1920s in the United States, when economists began to represent coal, oil and hydroelectricity in a single curve, relating them to energy units. For the experts, the fall in world coal consumption between the wars was in no way a sign of a transition from coal to oil or hydroelectricity. It was a temporary phenomenon linked to the high price of coal during the First World War and was mainly due to improvements in efficiency. By replacing steam engines with steam turbines, the efficiency of American thermal power stations doubled between 1917 and 1930. Electrification, by scrapping inefficient steam engines, made it possible to save coal, while paradoxically reinforcing its economic importance. (Scott Turner, 'The Mineral Industry', Department of Commerce, US Bureau of Mines, 1932, p. 12.)

hydroelectricity was also quickly refuted. Long before Geddes' flights of fancy, calculations had already shown that flat England would save just over a million tonnes of coal thanks to its rivers: a ridiculous amount compared with the 200 million tonnes burned at the time.[40] In the United States, where the potential for water power was much larger, hope lasted a little longer, but experts generally regarded hydropower as a means of conserving coal, certainly not as a replacement for it.[41] It is also striking to see the extent to which conservationists were concerned with the very long term, with the availability of coal in three or four centuries' time: proof if it were needed that the idea of transition was alien to them.[42] In 1915, Herbert Jevons, Stanley Jevons's son, stated that British coal consumption would peak in 2100 at 400 million tonnes a year, followed by stabilization at 300 million tonnes until . . . 2200.[43]

'The age of' and the historians

In the last third of the nineteenth century, the intellectual routine of indexing epochs with materials appeared in an ideological potpourri of industrial promotion, Malthusian fear of exhaustion, national anxiety, electric utopia and social reformism – all expressed in the prehistoric lexicon that befits the great evolutionist narratives. What is most surprising is the extent to which historians have accepted this strange vision of the past.

In early works on the 'Industrial Revolution' – by Arnold Toynbee, for example – coal was not central. The heart of the action was at the end of the eighteenth century, with the mechanization of the textile industry. Historians were more interested in the deleterious social effects of mechanization than in the replacement of muscle by steam. The inspiration came from Adam Smith and Marx rather than Jevons.[44] But at the beginning of the twentieth century, various concepts – organic economy, the first and second industrial revolutions – acclimatized 'the age of' narratives in history. For historians with philosophical pretensions – or philosophers with historical pretensions – erecting matter as a temporal marker provided ready-made explanations and gave an appearance of materialism to narratives which, ironically, were rather inspired by idealist philosophies of history. Material-stage history provided a convenient alibi for intellectuals who claimed that they had to rethink social, economic, historical and other issues from top to bottom because the material foundations of the world had suddenly changed. These *tabula rasa* intellectual tactics are ancient, commonplace and constantly renewed.

As early as 1903, the German historian Werner Sombart interpreted industrialization as a departure from the 'organic economy' and even proposed calculations of 'ghost acres' to illustrate its impact; for example, steam locomotives generated such an amount of energy that a quarter of Germany's surface area would have had to be dedicated to feeding the horses required to provide an equivalent amount of power.[45] While contemporary historians of the Industrial Revolution such as Rolf Peter Sieferle, E. Anthony Wrigley and Kenneth Pomeranz have adopted the term and the method, for the very conservative Sombart, the 'organic economy' served above all to characterize German identity. 'What differentiates the Germans from other nations,' he wrote, 'is the forest. The material culture of the northern countries was rooted in the forest before iron and other inorganic materials created a new one.'[46] Sombart contrasted this *Gemeinschaft* of forest, wood and use-value with the mineral economy of English capitalism based on machines, coal and iron. The Anglo-Saxon capitalist in his city of steel and concrete is like the wandering Jew in the desert: both 'are deprived of their relationship with mother earth. The sense of communion with all living things is destroyed, as is any true understanding of organic nature.'[47] The nineteenth century, he laments, saw the destruction of the organic economy through quantification, science and mechanization, and the substitution of mineral matter for living matter: coal for wood, steam for horses, phosphates for manure, chemical dyes for natural dyes.[48]

In the 1930s, the idea that the English industrial revolution was fundamentally an energy phenomenon became commonplace in the writings of public intellectuals trying to make sense of the economic crisis and 'technological unemployment'. They explained that the early 1900s saw the advent of a 'second industrial revolution' – American and electrical – a 'power revolution' that should be analysed in the light of the first: that of England and coal.[49] Machines receded into the background: 'the new thing, the really fundamental thing, the profoundly important thing that defines the Industrial Revolution is the substitution of other powers for human physical effort as the working energy of the world's production,'[50] wrote the London socialist Fred Henderson. The *Chicago Tribune* journalist Harper Leech made the same observation: intellectuals idolized or blamed machines without understanding that they were merely an emanation of coal: 'Modern mankind has been the passive beneficiary of the great Palaeozoic accident.' The first industrial revolution took place when 'the steam engine shifted the economic basis of Britain from her soil to the coal seams underneath',[51] and the second when energy became ubiquitous thanks to electricity. Here, energy thinking served a conservative ideology: just as Malthus and Ricardo were already obsolete in their time – because they had not grasped the upheaval introduced by James Watt – so, in the USA, Marxism and the class struggle no longer made any sense 'when labor, the muscular work of man is responsible for only a trifling fraction of all actual work performed . . . when 94% is done by coal, oil, natural gas, and waterpower'.[52]

Technics and Civilization is undoubtedly the masterpiece of the stagist literature of the 1930s. Its author, Lewis Mumford, takes elements from Geddes, Sombart and Oswald Spengler and claims to provide a history of 'the material foundations of Western civilization'.[53] In his book he identifies three successive phases – eotechnics, palaeotechnics and neotechnics – a more distinguished way of speaking of the ages of wood, coal and electricity that goes back to the prehistoric origin of all these tropes. The history of materials is conflated with the history of technology, which leads Mumford to certain aberrations. Iron is described as the 'universal material' of the nineteenth century, and Mumford is even astonished to see 'the techniques of wood surviving the age of metal'.[54] Like Geddes, but later than him, Mumford was still convinced that 'neotechnics' would abrogate the reign of coal, that they would save industrialization from the original sin of coal. Thanks to hydroelectricity, 'blue skies and clear waters will return'.[55] Better still, it would give birth to a planetary conscience, to a 'geotechnics' concerned with forests and the climate, because humanity would henceforth have to take care of nature – or at least of watercourses – to produce its energy.[56] It should be noted that in 1938, Mumford was recruited by the Pacific Northwest Regional Planning Commission (PNWRPC), an institution similar to the better-known Tennessee Valley Authority, which poured an enormous amount of concrete to develop the Columbia river with hydroelectric dams and other infrastructure.[57]

Hiroshima and Nagasaki caused an outburst of stagism. 'We enter a New Era: the Atomic Age' was the headline in the *New York Times*.[58] In France, *Le Monde* and *L'Aurore* announced 'a scientific revolution'[59] at the time of the destruction of the two Japanese cities. On 18 August, well before Gunther Anders, an American journalist announced 'the obsolescence of man'. In the 1950s, the 'atomic age' was everywhere. Everything had to be reread in its light: physics, war, peace, law and ethics, of course, but also *Le savoir vivre à l'âge atomique* and *L'éducation catholique de nos filles à l'âge atomique.* A French doctor even dared this title: *Comment prévenir la cellulite, fléau de l'âge atomique* ('How to prevent cellulite, the scourge of the atomic age').[60] Virgil Jordan, the editor of *Business Week*, wrote without batting an eyelid in 1946: 'Thanks to atomic energy, anything can now be made from anything, or even from nothing, anywhere in the world, in any quantity and at no cost.'[61]

Despite the disappointments of the atomic age, stagism did not disappear. After the atom, it was the computer that designated the new era, and like many of the other 'ages of' that had preceded it, 'Information Age' appeared in the title of a computer magazine in 1978, before becoming the title of a famous sociological trilogy.[62] In the 1970s, there was a vogue, especially in the United States, for the 'solar age'. And today, in the face of global warming, a fantastical history of energy is fuelling the return of the crudest stagism, for example Jeremy Rifkin's books announcing a 'third industrial revolution' based on hydrogen, which would follow the first one based on coal and the second industrial revolution based on oil.[63]

More surprisingly, in the historical studies too, the 'ages of' endure. The British Library catalogue even shows a resurgence of publications with a material chrononym in their titles.[64] Recent historiography, rightly concerned with the environment and resources, has given a second life to the energy stagism of the last century: the 'industrial revolution', relativized by twenty years of economic history, has been rehabilitated as a 'transition' from wood to coal, as the passage from an 'organic economy' to a 'mineral economy'. However, since the beginning of the twentieth century, as stagism spread through popular culture and among intellectuals, experts had painted a very different picture of material history: a history not of phases and ages, but of stratification and symbiosis.

Whether for obscuring human muscular work, for advocating social reform or for claiming power for engineers, age-of-ism has always had political overtones. But with climate change, its persistence has become truly dangerous. For it is this ordinary historical culture that explains the ease with which, in the face of climate change, the notion of an 'energy transition' has become self-evident and could appear as a solid and reassuring notion, a notion anchored in history. Whereas in reality, this future had no past whatsoever.