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One of the most important issues facing humanity is the prospect of global climate change, brought about primarily by our dependence on fossil fuels. If we continue to use the present mix of fuels even as the world's economy and population grow we will invite very serious consequences. Common sense dictates that we switch to more renewable and sustainable sources of energy.

This book provides detailed yet easily understandable information about sustainable energy alternatives in the context of growing public concern about climate change, the impending fuel crisis and environmental degradation. It describes the history of energy use and the factors that have led to the current interest in energy alternatives, and assesses the chances of renewable energy replacing fossil fuels.

The authors manage to make a highly complex and often intimidating subject not only accessible but also engaging and entertaining. This book unpacks but never simplifies the science of energy, leavening the more technical passages with anecdotes, metaphors, examples and imagery. By also dealing with the history, politics and economics of energy use, it offers both scientific and non-scientific readers a deeper understanding of one of the most important issues of our age.

Gian Andrea Pagnoni is a lecturer at the University of Ferrara. He has published eleven books on travel and science in his native Italy, as well as numerous scientific papers on environmental issues. His most recent book, *Impianti a biomasse per la produzione di energia* (Biomass plants for energy production), was published in 2011. In 2001, he co-founded the Istituto Delta di Ecologia Applicata Srl (the Delta Institute of Applied Ecology), an independent consultancy for environmental assessments and environmental project management. In recent years, he has focused mainly on the fields of renewable energy and environmental conservation.

Stephen Roche heads the publication department of the UNESCO Institute for Lifelong Learning in Hamburg, Germany, and edits a scholarly journal, the *International Review of Education*. From 2005 to 2012, he ran an agency, Network Translators, which translated or edited more than 100 books, reports and research papers on architecture, economics, education, environmental science, history and international development. From 2009 to 2012, he also worked at the University of Hamburg, developing and teaching courses in academic writing and English literature.

Everything in the universe may be described in terms of energy. Galaxies, stars, molecules, and atoms may be regarded as organizations of energy. Living organisms may be looked upon as engines which operate by means of energy derived directly or indirectly from the sun. The civilizations, or cultures of mankind, also, may be regarded as a form or organization of energy.

Leslie White, 1943

Preface

This book began with a skiing trip in the Alps in January 2010. Gian Andrea and I had known each other since 1990, when, as students, we shared an apartment in Ireland. Having lost touch for more than a decade, we had recently renewed the friendship. Conversations between old friends tend to cover a lot of ground very quickly. We filled each other in on relationships past and present, on travels and travails, past and current work, and where we thought we were heading. I'd been working as a translator and editor for several years. Gian Andrea had set up an environmental consulting company with other scientists from the University of Ferrara and balanced this work with additional teaching and writing.

He had always been a practical man. In kitchen table conversations during our student days, he didn't shy away from controversial positions, exposing the contradictions within many closely held beliefs. He once declared, to the horror of several humanities' students, that he felt no attachment to language, and that the disappearance of his native Italian would be of no consequence provided it were replaced by a more efficient substitute, such as, for example, English. I was bemused and a little shocked by his lack of sentimentality, but I appreciated his dedication to objectivity.

At the time of the skiing trip I was starting to tire of my ventriloquial craft, so when he suggested an alternative, I was curious. "If you're tired of working on other people's books, you should write your own. In fact, we could write one together." I had recently attended the UN Climate Change Conference in Copenhagen, so the point where my interests and his expertise most clearly intersected was obvious: sustainable energy.

The process began with a series of Skype conversations, leading to a proposal we jointly composed using Google Drive. As the project progressed, Skype and Google became indispensable tools, allowing for a kind of collaboration that would not have been possible without them. Though we were living about 1,000 kilometres apart, most evenings, for a couple of hours, we stepped into the same virtual room. Most of the sections began with a conversation, during which Gian Andrea introduced a particular idea or data, and I, by a kind of Socratic process, teased out what that meant in layman's terms. Once we felt we had arrived at an explanation that conveyed the essence without compromising the scientific fact, we composed the particular section. Eventually, we corrected these together and discussed figures, captions and changes. We probably wrote ten times the number of words currently in the book. The result is neither the work of a scientist simplifying things for the layman nor of the layman coming to grips with science; rather, it is a marriage of the two.

Stephen Roche

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Introduction

Renewable energy, far from being a new idea, was the norm for most of human history. The ability, developed in the late eighteenth century, to harness the 'fossilised' energy of coal and oil on a large scale transformed human societies. It was no accident that the explosion of the Earth's human population, from roughly 1 billion in 1800 to more than 6 billion in 2000, coincided with this energy revolution. The question people have been asking in increasing numbers for the last fifty years is, "Can it go on like this?" Most are in agreement that it can't. Whether one views climate change, population growth or resource depletion as the greatest threat to human survival, the basic problem is the same: there are limits to what our planet can provide or absorb. The renaissance of renewables is inevitable because sooner or later the oil, gas and coal will run out; because by releasing in decades the carbon absorbed over millennia we are choking the planet; and, lastly, because of economics – whereas fossil fuels are likely to become more expensive over time, renewables can only get cheaper.

This book covers most of the issues related to renewable and sustainable energy – from the purely technical to the historical, political, social and economic. It begins with a broad introduction to energy, both as a concept and a practicality, outlining the history of human energy use, profiling our current consumption, and assessing likely prospects for the future. In doing so, it uncovers and unpacks the various factors that influence our energy choices.

This book is also about the transition we must make, and indeed have already begun to make. It explains the different factors influencing that transition and the likely sacrifices that will be required. Stephen lives in Germany, so we are familiar with the debates that led to the adoption of the 'Energiewende' (literally, energy transition) in 2011 in the aftermath of the Fukushima nuclear accident in Japan.

This created a critical mass of support among the German public for a departure from nuclear energy. At that time Germany had only seventeen nuclear power plants in operation, supplying about 18 per cent of the nation's electricity. As these are phased out, they are mostly being replaced in the short term by brown coal (of which Germany has plenty) and Russian natural gas, which at the time of writing entails a precarious dependency. Renewables supply about 23 per cent of Germany's electricity and about 14 per cent of its overall energy consumption.[1] These figures may impress when compared with those of most other countries, but on their own they show that the 'energy transition' is still in its infancy.

The transition to sustainable energy will not only transform the way energy is generated but also the way it is traded. Already, the model of electricity supply devised by Thomas Edison in the early twentieth century – a relatively small number of very large power stations that supply power via a ubiquitous grid – is starting to appear outdated. Whereas a generation ago, many energy utilities prospered by operating large power plants of one particular type, many of these giant companies are now investing in a wide range of alternatives. In the United States alone, there are now close to 500,000 solar plants in operation. Most of these are small and are installed on the roofs of private homes. A quarter of them were installed in 2013 alone (Biello 2014).

Every human intervention in the natural environment has an impact. In the cases of hydropower and bioenergy, the impacts may even exceed – in terms of the environmental and social disruption – those of fossil or nuclear power. This book therefore is not biased in favour of renewables but considers the price of the 'energy transition' in terms of environmental and social impacts as well as economics.

Every movement begins with an idea, and once an idea has been widely embraced, change can follow quickly. We believe that the most immediate obstacle to a peaceful energy transition is not economic, infrastructural or political. It lies in the ability of large numbers of people to not merely reject the existing system but to imagine a new paradigm. We hope that this book can help to fill some of the gaps in your understanding of energy, and help you develop a clearer idea of how the energy transition can occur.

Gian Andrea Pagnoni

[1] Source for all German energy statistics: German Association of Energy and Water Industries (Bundesverband der Energie- und Wasserwirtschaft [BDEW]) http://www.bdew.de/.

1

What Is Energy?

1.1 Aristotle in Times Square

The term ‘energy’ has become ubiquitous, as likely to be heard in a yoga class as at a physics lecture. In its everyday use, it has become synonymous with force, vigour, well-being and a certain kind of atmosphere. We talk about people or places having energy, a certain kind of energy, or lacking it altogether. We’ve become so used to using the words ‘energy’ and ‘energetic’ as pliant descriptors that we’re liable to overlook their scientific significance.

A first-time visitor to Times Square, the heart of one of the world’s busiest cities, is likely to first comment on the ‘energy’ of the place. But does this use of the term bear any relation to its scientific meaning? The Greek term ἐνέργεια (*energeia*), the origin of the English word, was probably coined by Aristotle. It combines the prefix *en*, meaning ‘in’ or ‘at’, with *ergon*, meaning ‘action’ or ‘work’. According to Aristotle, all living beings are defined by this attribute; they are ‘at work’, in contrast to inactive, inanimate objects. So *energeia*, for Aristotle, was intimately connected to movement. This philosophical concept of energy remained for more than 2,000 years the main usage of the term. As late as 1737, the philosopher David Hume wrote that there were “no ideas, which occur in metaphysics, more obscure and uncertain, than those of power, force, energy or necessary connexion”.

The first attempts to define energy in scientific terms date back to the seventeenth century. Isaac Newton established that the same force (gravity) which causes an apple to fall from a tree also determines the movement of the planets around the sun. Newton’s contemporary Gottfried Leibniz identified something he called *vis viva* (literally ‘living force’), the force of any moving thing. Leibniz began the process of quantifying energy when he concluded that while the force of a moving object depends both on its mass (weight) and its velocity (speed), velocity was far more important than mass. In other words, a light but fast-moving object has far more force than a heavy but slow-moving one. Just imagine catching a basketball, which weighs about 600 grams, thrown by a teammate. Now compare this with the impact of a 10-gram bullet fired from a gun.

The human understanding of energy took a huge leap forward during the Industrial Revolution, pioneered by industrialists who were motivated as much by commercial ambition as by scientific enquiry. For them, energy was not an abstract idea; it was the force needed to drive the machines that were rapidly replacing human and animal labour. They therefore redefined energy as the ability to perform work. This remains the most common definition to this day. But what exactly do we mean by work? An ox pulling a plough is clearly at work. The animal's 'biological' energy is converted into furrows. In scientific terms, the ox exerts a force over a distance. Since prehistoric times, humankind's work, like that of the ox, has mainly involved moving objects, whether spears, arrows, goods or the plough. By the mid-eighteenth century, it was the turn of machines, and in order to build and use those machines, people needed to understand and quantify energy.

Most work requires more than the mere application of energy. To be effective, that energy must be concentrated. We see this when we open a bottle of beer or a soft drink. It would take a very strong (and thick-skinned) person to tear the cap from the bottle without using a tool. However, even a young child can perform the same task with a bottle opener. This is because the opener works as a lever, concentrating the energy at the point where it is needed to remove the cap. When energy is concentrated not in terms of space (such as at the rim of a bottle) but in terms of time, the concept of power comes into play. Most people have gone through the ordeal of moving house at least once. If we do the move ourselves, the time required will depend largely on the muscle power we can muster from obliging friends and family members. If you have a few bodybuilders in the family, the move will be quick. If you are relying mainly on your kids, you should hire the van for the entire week. This, essentially, is the difference between energy and power: power is the *rate* at which energy is generated and consumed to perform work.

James Watt (1736–1819) was particularly interested in power. He spent most of his life improving the steam engine, which works by heating water to form steam. The vapour occupies a greater volume than liquid water does and so pushes upwards, raising a piston, just as water boiling in a pot raises the lid. Thus, Watt (and others before him) succeeded in converting the energy of heat into the energy of movement, which can be harnessed to perform a wide variety of tasks, from pumping water to turning a wheel. To convince his customers of his machine's efficacy, Watt came up with the term 'horsepower', which explains its power output relative to the main energy source of his day, the draft horse. This term, which is still used to rate certain types of engines, was later, fittingly, replaced by the *watt* as the international unit of power.

Converting Energy

Watt's horsepower measured the output of his machines, but it fell to another entrepreneur-engineer to measure the transformation of one form of energy to another. While exploring ways to improve his brewery, James Joule (1818–1889) made a breakthrough. He had been thinking of changing over from the steam engine to the newly developed electric motor. Before doing so, he wanted to compare the amount of work that could be performed by each machine. Joule constructed a device resembling an egg beater immersed in a jar of water, and he used a weight and pulley to turn the blades of the 'beater' (see Figure 1.1). The movement of the water molecules created heat, which Joule was able to measure using a thermometer. The greater the weight (force) he used, the faster the beater turned, and the greater the rise in temperature. In this way, he discovered a simple yet remarkably accurate way of measuring the relationship between work and heat.

Joule's experiment led to the formulation of one of the most important principles of physics: the first law of thermodynamics. This states that energy can be neither created nor destroyed, but merely changed from one form to another. Think of what happens when a car brakes: the energy of its movement is not lost, just converted into another form of energy. The brake pads, discs and surrounding air are warmer than they were before the driver braked. This principle is crucial to understanding how energy can be generated and used.

The Enigma of Energy

By the twentieth century, scientists had learned to quantify and measure energy, yet there remained something inherently mysterious

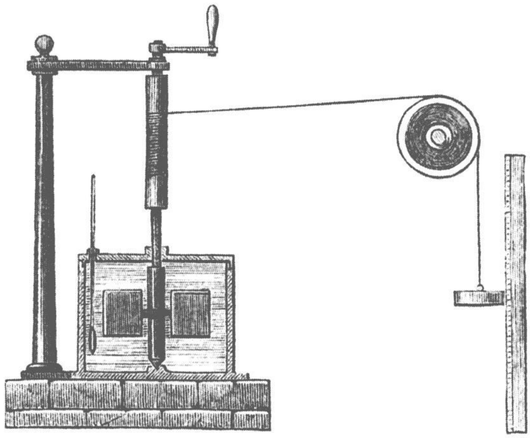

Figure 1.1. Joule's apparatus for measuring the relationship between work and heat. The fall of the weight causes the blades to turn, stirring – and thus heating – the water inside the container (calorimeter). A thermometer measures the rising temperature.

about the concept. Richard Feynman, one of the towering figures of modern physics, went as far as to admit that "in physics today, we have no knowledge of what energy is" (1970).

Energy, as we currently understand it, is force, work and power. It is at the heart of what it means to be alive: the ability to manipulate our environment to meet our needs. Thus, Aristotle's definition of energy remains essentially valid today. If the father of Western philosophy were to have stepped into a time machine that touched down on Times Square, he would recognise around him the principle of energy in action, through two factors: motion and work.

1.2 Energy: What Gets Lost in 'Translation'

Robert Frost memorably defined poetry as "what gets lost in translation." Just as meaning is inevitably lost as ideas are converted from one language to another, there is no way to convert energy without loss. Energy efficiency, like translation, is merely about minimizing that loss.

As a teacher, I always require that my students work in groups, where each person's grade is influenced by that of the whole group. It often happens that a student complains about a group-mate, typically that he or she is not pulling their weight and therefore jeopardising