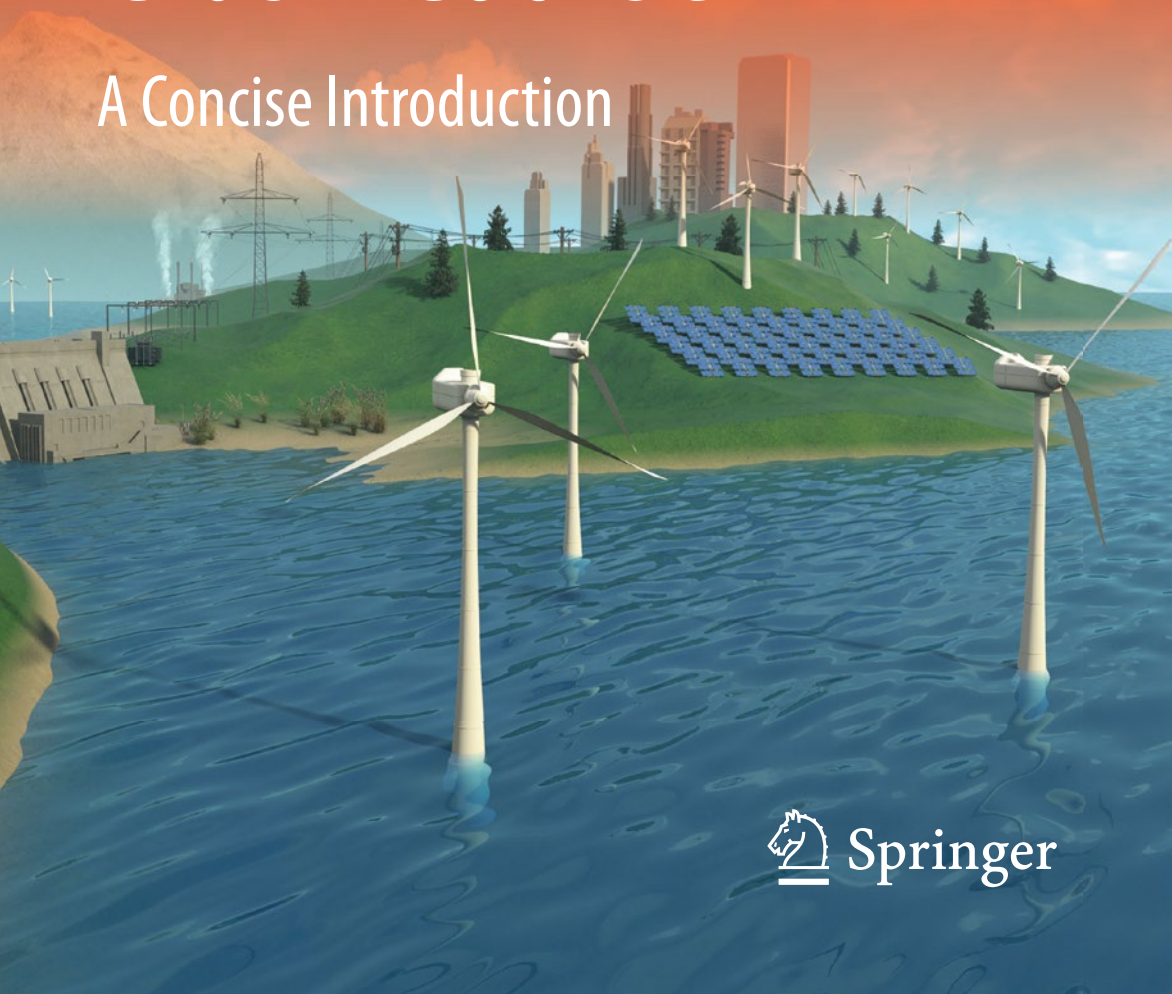


Eklas Hossain
Slobodan Petrovic

Renewable Energy Crash Course

A Concise Introduction



 Springer

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Preface

This book was created over a period of more than 10 years and is based on the experience from classes taught as part of the renewable energy engineering program at the Oregon Institute of Technology. More than 500 program graduates, who work now in all aspects of renewable energy, have indirectly participated in the book creation through their insights, good and bad exams, assignments, and mostly passion to contribute to progress in energy generation and to protect the environment.

While the authors have collective experience in the energy field of close to 50 years in academia, industry, research labs, and humanitarian use of renewable energy, the educational approach when writing this book came mainly from direct experience in the classrooms and from the course notes. Over the years, the instructional approaches to teaching the topic were evolving until the right mix of the fundamental principles, technology description, device or plant designs, and environmental impact was established.

The book is an introduction to renewable energy, and it is deliberately written using easily understandable terminology and the right amount of information, without the need for upper-level mathematics or science. Every chapter provides practical examples, case studies, and simple exercises.

This book is primarily intended for engineering and science students, but also students from other disciplines with a general interest in renewable energy and curious high school students and professionals who need a quick introduction to renewable energy.

The authors hope that the book will inspire readers, who are first introduced to the subject, to develop passion and continue the study of renewable energy. The excitement of learning about solar and wind energy, hydroelectricity and biomass, ocean and geothermal energy, energy storage, and grid integration of renewables might be a step towards a better future for all.

Key Features of This Book

- Simple language
- Highly focused content
- A case study at the end of each chapter
- Concise, precise, and updated

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Acknowledgments

We would like to thank hundreds of renewable energy engineering students, who have inspired us, with their insights, creativity and passion, to put our experiences in teaching renewable energy into a book.

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Renewable Energy Definition

Renewable energy can be defined as energy that will not deplete naturally and can be extracted for an indefinite time. Renewable energy sources such as solar, wind, hydro, bioenergy, ocean energy, and geothermal are freely available from nature and do not harm the environment when converted to energy in the way fossil fuels or nuclear energy do. The carbon emission from utilizing renewable energy is minimal compared to energy conversion from fossil fuels or nuclear processes.

The sustainability definition includes a broader meaning and refers to energy generation that is not depletable on a human timescale, which does not lead to emission of greenhouse gases or other pollutants and which does not contribute to social injustice or geopolitical imbalance.

Energy Basics

Energy is defined as the ability to do useful work. While this may sound abstract and difficult to conceptualize for those new to science and engineering, it should be clear to all readers that energy is critical for sustaining life on Earth. It is also largely understood that energy may be converted from one form to another and that there are two basic expressions of energy, potential and kinetic, and that some energy is stored.

Examples of the stored form of energy are chemical energy in gasoline and gravitational energy of water ($E = mgh$). Other forms of energy include mechanical energy, thermal energy, which is kinetic energy of atoms and molecules, the energy of light (electromagnetic radiation, $E = h \times \nu$), electrical energy, magnetic energy, atomic energy, molecular energy, and the mass-energy interaction as expressed in Einstein's famous equation ($E = mc^2$).

Fundamentally, there are only three original sources of energy, solar nuclear fusion, heat from the core of the earth, composed almost equal parts of residual heat from the early stages of the planet and from nuclear processes in the Earth's crust, and energy from the rotation of the Earth and the moon. All energy on the Earth comes from these original sources of energy, which subsequently create primary or unprocessed energy. Examples of primary energy include fossil fuels (coal, oil, and natural gas) and renewable energy such as hydroelectric, solar, wind, biomass, ocean, and geothermal. The primary energy is then changed into effective energy that reaches the end-user in the form of electricity, heat, steam, gas, or hot water.

The Physical Laws of Energy

According to the First Law of Thermodynamics, energy is conserved, and it cannot be created or destroyed and can only be converted from one form to another. This also means that the total energy of the universe is constant. A system under observation may gain or lose energy, but the same amount must be lost or gained by the environment (or the surroundings). Energy is not created in the sun but converted from nuclear fusion energy into radiant energy.

A power plant, for example, a renewable energy power plant such as hydroelectric or solar, or a fossil fuel coal power plant, does not create energy—it only converts it from one form to another.

It should be understood by the reader that conservation of energy is different from *energy* conservation, which means using energy wisely.

Power

Power is mathematically the derivative of energy. It is the change in energy over time. The unit for power is Watt (W). For example, if 1 J of energy is given by a system in one second, power of 1 W is applied. Two systems may have an equal amount of energy stored, for example, in a battery, but if one system is able to deliver that energy faster than the other then, then that system is more powerful.

Another way to define power is to describe it as the production of energy. For instance, if a power plant operates at 1 GW of power, it produces 1 billion J of energy every second.

Energy Units and Conversions

Energy is the product of power and time and is most commonly expressed in practical systems in kilowatt-hours (kWh) instead of Joules, the unit of measurement used in physics. For example, if a power plant generates power of 1 MW (1×10^6 W) for 1 h, it produces 1 MWh (1×10^6 Wh) or energy.

Besides kWh, there are several other ways to express energy (Table 1.1).

Table 1.1 Energy units and conversions

Conversions	kJ	kcal	kWh	m ³ gas	BTU	Therms
1000 J = 1 kJ	1	0.239	0.000278	0.000032	0.9478	0.0000095
1000 cal = 1 kcal	4.187	1	0.00116	0.00013	3.968	0.0000397
= 1 kWh	3600	860	1	0.113	3412	0.0341
1 m ³ natural gas	31,736	7580	8.816	1	30,080	0.301
1 BTU	1.055	0.252	0.000293	0.000033	1	0.00001
Therms	105,480	25,200	29.3	3.326	99,976	1

There are also practical energy units based on oil and the fact that when oil is burned with oxygen, its chemical energy is converted to heat energy. One tonne of oil equivalent (toe) is simply the heat energy released in the complete combustion of 1000 kg of oil that produces on average 41.88 GJ.

Another unit used to measure the amount of energy is a barrel, which is 42 US gallons (35 Imperial or British gallons) or about 160 L. On average, there are 7.33 barrels in a tonne of oil. The energy content of 1 barrel is approximately 5.71 GJ, which is the unit called 1 barrel of oil equivalent (boe). Typically, it is expressed in million barrels daily (Mbd). The energy content of gasoline is about 44 GJ/tonne or 33 MJ/L.

There are also energy units based on coal. One tonne of coal equivalent (tce) is the amount of heat energy released when 1 metric ton of coal is burned. Although variations are significant between coal types, it is accepted that this value is equivalent to 28 GJ.

A British Thermal Unit (BTU) is the heat energy required to warm 1 pound of water by 1 °F. It equals 1055 J, while 1 therm is a large unit equal to 100,000 BTU.

One quad is a quadrillion BTUs equal to 1.055 EJ. Finally, 1 calorie (cal) is the heat energy needed to warm up 1 g of water by 1 °C and is equal to 4.19 J.

Energy Generation

The global energy consumption in 2019 was 580 EJ (580×10^{18} J) or 0.161 EWh (161×10^{12} kWh). A breakdown of the contributions from different technologies is shown in Table 1.2 for the United States and the world.

Renewables include hydroelectric, biomass, wind, solar photovoltaic, and geothermal. The data in the table reveals that fossil fuels combined contribute to over 84% of all energy produced in the world and about 70% of the US generation.

Fossil Fuel Reserves

Fossil fuels originate from organic matter that decomposed many hundreds of thousands or millions of years ago. Oil, coal, and natural gas used today to generate energy are the biological materials formed in the distant past under the conditions of heat and pressure. Because there are finite quantities of fossil fuels available in

Table 1.2 A breakdown in percentage of the energy generation technologies (sometimes called energy mix) for the United States and the world in 2019

Resource	% of U.S. Production, 2019 [1]	% of Global Production, 2019 [2]
Coal	11.3	27.04
Natural gas	32.1	24.23
Oil/ petroleum	36.7	33.06
Nuclear	8.5	4.27
Renewables	11.5	11.42

the Earth's crust, their future availability depends on the ratio of the rate of use and the number of reserves. While new fossil fuel material is still formed, the time scale of formation of millions of years means that we are now exploiting the reserves, and it is clear that the present rate of extraction will inevitably lead to depletion.

The quantity of the crude oil and natural gas reserves that can be recovered and exploited is often described using the so-called Hubbert Curve. It was established in 1956 by American geophysicist M. King Hubbert that the explorations of crude oil from a certain region first increase after discovery but eventually reach a peak after which the amount gradually decreases until depletion. The main conclusion from the Hubbert's historical resources model of crude oil discovery and exploitation is that there are finite reserves of crude oil in a certain region and, by extension, on Earth. The quantity of reserves or availability over time depends on the rate of extraction and follows roughly a bell-shaped curve, leading in the end to a complete depletion of reserves. For example, crude oil production in the United States peaked in the early 1970s while in the polar regions peaked around 2015. The exact shape of the curves is different for each region of the world; however, it is obvious that the peak in the global crude oil availability was in the first part of the twenty-first century, and the amount of crude oil available in the world is now on a sharp decline.

It is interesting to look at the availability of proven reserves and to relate it to current production (extraction) rates. The resulting number is the reserves-to-production (R/P) ratio or RPR, which is the ratio of the remaining amount of a nonrenewable resource to the rate of extraction or production. This ratio predicts how many more years the resource might last at a certain rate of extraction.

Consequently, it is generally understood that coal will remain a viable fossil fuel source for several more centuries, but oil and natural gas are expected to completely diminish in the next few decades at the most. For about two centuries, since oil was discovered in Titusville, PA, in 1859, the world's economically recoverable oil reserves have been nearly consumed, while it took millions of years for this resource to form from biomass.

The diminishing reserves of crude oil and natural gas, compounded by the harmful emissions from burning fossil fuels, have created the biggest turning point in the history of energy generation. The disadvantages of continued reliance on fossil fuels are obvious, making the case for the development of renewable energy technologies.

Renewable Energy Sources

The renewable energy sources and corresponding energy generation technologies include bioenergy, hydro energy, solar, wind, ocean, and geothermal.

Bioenergy is used in the form of wood, biomass, and crops (such as sugar cane) to produce heat and electricity. Wood and other bioenergy feedstock have the potential to be sustainable fuel sources if the rate of reforestation exceeds the rate of use. If managed properly, bioenergy can be exploited without a net increase in CO₂ emission. Bioenergy can also be converted to biofuels used for transportation. Although gaining global importance, bioenergy is currently a significant energy source only in developing countries.

Hydropower is the largest renewable energy contributor providing around 17% of the world's electricity in hydroelectric power plants. On a small scale, hydropower satisfies the sustainability criteria with no adverse environmental impact. However, on a large scale, massive dam installations result in major interruptions to the environment and can further lead to methane gas emissions through anaerobic decay of vegetation.

Solar energy can be utilized in two ways, to produce electricity in a photovoltaic reaction or heat in solar thermal processes. The source of solar energy is in the continuous nuclear fusion reactions between hydrogen isotope atoms inside the Sun that create temperatures on the surface of roughly 6000 °C. Only a small fraction of the energy of the Sun reaches the Earth.

Wind energy is an indirect manifestation of the energy of the Sun. It is one of the most important renewable energy technologies. The wind turbines can be installed on the land and offshore. A special case of wind energy utilization is harnessing the power of ocean waves.

The tidal energy is created by the gravitational pull of the moon on the world's oceans. The technology involves installing water turbines where the topography of shores amplifies tidal effects. The concerns about tidal energy are extremely high capital costs and the impact on the wildlife.

The origin of geothermal energy is in the Earth's internal heat, which comes from the radioactive decay of long-lived elements and the residual heat of formation. The most convenient way to take advantage of geothermal energy is to capture the underground water at high temperatures. The extracted hot water can be used for heating or steam can be used to generate electricity. Geothermal energy is renewable on a larger scale, but it can run out locally.

Case Study: Countries with 100% Renewable Energy Generation Energy is primarily required for electricity generation and transportation purposes and can be generated using different forms of renewable energy. This initial case study demonstrates how some countries with favorable resource distribution have accomplished electricity generation largely or completely based on renewable energy sources. The list of countries mostly or fully converted to renewables for power generation includes Denmark (69.4%), Brazil (75%), Austria (80%), Norway (98.5%), Costa Rica (99%), Paraguay (100%), and Iceland (100%).