

# Preface

Carbon is the basis of life on our planet (and, possibly, in the Universe). We owe our good fortune to carbon-bearing fossil fuels (carbon fuels) that powered the Industrial Revolution and brought about the unprecedented standard of living we currently enjoy. Global economy runs on energy, and energy runs on carbon fuels: virtually all goods and services require their input, and, as the demand for these goods and services keeps growing, so does the amount of carbon fuels consumed. Because of the most critical role carbon fuels played and continue playing in the making and sustaining of our industrial civilization, the latter is often called *Carbon Civilization*.

Just a few years ago, a prevailing opinion among experts was that the concerns about “oil peak” and looming depletion of oil and gas reserves would drive their prices so high that switching from fossil fuels to alternative energy sources would become inevitable in the near future. That judgment has proved illusive. Thanks to technological innovations, crude oil and gas production is now growing in many countries; the world seems to be leaving behind the worst fears about resource scarcity and moving toward the new opportunities presented by the potential resource abundance.

Because of the incredible convenience of carbon fuels, our entire way of life is physically constructed around them; we became heavily addicted to carbon fuels and invested enormous resources in their infrastructure that proved extremely profitable. It is clear that neither developed nor developing countries are willing or will be able to break the fossil fuel addiction anytime soon, because for a significant part of our planet’s population burning more and more fossil fuels is the only way of getting out of energy poverty and improving their standard of living.

The Secretary General of the Organization of Economic Cooperation and Development (OECD), Angel Gurría, recently warned about the powerful “carbon entanglement” factor, which will make the introduction of alternative energy sources to the market extremely difficult as they will be “swimming against very strong tides.” The carbon entanglement paradigm is the primary reason for the very slow and modest progress of carbon mitigation and climate change policies over the last decades. All the ongoing trends and energy scenarios (even “optimistic” ones) point

to the world economy moving along the carbon-intensive path until at least the middle of the century and it could be much longer.

Recently, carbon fuels received a lot of negative publicity; it is impossible to pick up a newspaper or watch TV news without being reminded that they are responsible for many troubles on our planet: air pollution and health problems, oil spills and catastrophic explosions, acid rains and the disappearance of biospecies, changes in climate patterns, and other ecological cataclysms. At no point in history, have we come more close to the realization of potential risks of the high-carbon economic model. At this junction, society has to make important choices with regard to the present and future role of carbon fuels. Success will depend on a significant decoupling of energy use from economic activity, which would require changes in economic structure, technology development, and individual behavior. If we learned how to extract energy from carbon fuels without harming our environment, that would have solved many problems and opened the path to a cleaner and brighter energy future. But, is it technically feasible, and, if so, could it be done within a reasonable time frame and cost?

This book attempts to answer these and many other questions with regard to the future role of carbon fuels in the carbon-constrained world. The major tenor of this book is about decoupling energy from carbon through an approach called “decarbonization,” which aims at eliminating or drastically reducing the amount of carbon dioxide (CO<sub>2</sub>) emitted from the use of primary fossil fuel resources. Many experts believe that the inclusion of fossil fuel decarbonization in the portfolio of carbon mitigation options would greatly facilitate achieving “safe” atmospheric CO<sub>2</sub> stabilization goals, and it may potentially extend the fossil fuel era by perhaps 100 years (purportedly) without an adverse impact on our planet’s ecosystems and inhabitants. However, opponents of this approach are concerned that it could provide only a temporary relief, and would make humankind even more dependent on fossil fuels, thus making the necessary changes later even more difficult.

In a broader context of decarbonizing the fossil fuel-based economy, this book examines three main decarbonization strategies: (1) *carbon reduction* (through energy efficiency improvements and energy conservation), (2) *carbon rejection* (through carbon capture and storage (CCS)), and (3) *carbon abandonment* (through switching to zero-carbon energy sources and fuels, such as nuclear, renewables, hydrogen, biofuels). It highlights the current status of science and technology as well as economic, environmental, societal, and commercial development aspects of the decarbonization concept.

The second major motif of this book is CO<sub>2</sub>. Many people look at CO<sub>2</sub> only in negative light and consider it an unfortunate by-product of our techno-civilization and a noxious gas creating lots of problems: from asphyxiation to climate change. In May 2013, the researchers monitoring atmospheric CO<sub>2</sub> concentration at Mauna Loa Observatory in Hawaii reported that for the first time since humans became humans, the CO<sub>2</sub> concentration in the air reached 400 parts per million (ppm) (or 0.04 vol.%). Some people see this as an alarming and ominous milestone with grave implications for humankind, but for others it is just a number. Many are

puzzled: how it is even possible that extra few ppm of CO<sub>2</sub> in air could do such an enormous harm to our habitat.

This volume is a brief handbook of CO<sub>2</sub>—from its origins on our planet to its role in making our planet inhabitable, to its function in providing energy and fuels to humans, to its utility as a valuable industrial resource. The state-of-the-art technologies and commercial processes for CO<sub>2</sub> capture, transport and storage, as well as its conversion to value-added products and clean fuels are highlighted in this book. It attempts to prove that CO<sub>2</sub> is not only a cause of problems, but it could be part of the solution by reducing our dependence on petroleum-based fuels and feedstocks.

The book is organized in 11 chapters starting with the introductory Chap. 1 describing a brief history of carbon fuels, their origin, diversity, abundance, and crucial role in sustaining our well-being in the past, present, and future. The chapter examines the main grounds of our addiction to carbon fuels, controversies around “Peak Oil” theory, and a new paradigm of dealing with the “tide” of carbon fuels and coping with their environmental impact. Chapter 2 explores what is so unique about the CO<sub>2</sub> molecule that makes it so essential for humans’ survival. Without CO<sub>2</sub> our planet would be too cold and not livable, but it also could become too hot if too much of CO<sub>2</sub> is in the atmosphere. Where is the “sweet spot”? This chapter seeks to address this and other questions by explaining such phenomena as greenhouse effect, radiative forcing, global warming potential, global carbon cycle, and other factors that control the livability of our planet and are linked to unique physicochemical properties of CO<sub>2</sub>.

Carbon fuels as the main source of anthropogenic CO<sub>2</sub> emissions is the topic of Chap. 3. It classifies major CO<sub>2</sub> sources by industrial sector, scale of emissions, CO<sub>2</sub> content in flue gases, and geographical distribution; current and future trends in CO<sub>2</sub> emission sources are analyzed. Chapter 4 examines the issue of “acceptable risk” limits of atmospheric CO<sub>2</sub> concentrations in terms of the global mean temperature rise, and analyzes proposed CO<sub>2</sub> stabilization scenarios and roadmaps. The historical trends in carbon intensity of energy and the current status of decarbonization of global economy using the Kaya Identity (KI) modeling tool are examined in Chap. 5. The KI analysis shows that dramatic reductions in the energy and carbon intensities of world economy would be necessary to stop and reverse current recarbonizing trends, and it points to prospective carbon mitigation options helping reach that goal. Chapter 6 seeks to address the question, are there alternative carbon-neutral solutions ready to replace incumbent fossil fuel technologies without major perturbations affecting the health of the world economy? The chapter puts nuclear and renewable energy technologies in spotlight as the major decarbonizing techniques.

The role of CCS as a critical component of the portfolio of carbon mitigation options is addressed in detail in Chap. 7. The state-of-the-art technologies encompassing all three major stages of the CCS chain—CO<sub>2</sub> capture, transport and storage, as well as economic, environmental, and societal aspects of the large-scale CCS deployment—are examined in this chapter. Chapter 8 focuses on the range of strategies and pathways to transitioning from high-carbon to low- and zero-carbon energy carriers and fuels. The increasing role of the integrated electricity, methane, and hydrogen grids in the decarbonization of the global energy system is emphasized.

Carbon capture and utilization (CCU) as an important carbon abatement option is highlighted in Chap. 9. Existing and emerging CO<sub>2</sub> utilization technologies are analyzed in terms of their technological maturity, environmental impact, potential revenue generation, and carbon mitigation potential. Chapter 10 identifies the opportunities for carbon-negative technologies such as bioenergy coupled with CCS (Bio-CCS), biochar production, and removal of CO<sub>2</sub> from atmosphere (air capture). Chapter 11 is concerned with the range of radical geoengineering strategies aiming at reducing CO<sub>2</sub> levels in the atmosphere. The current status of major geoengineering projects, their economic feasibility, technical challenges, and risks associated with the global deployment of the technology are analyzed in this chapter.

The uniqueness of this book is that it takes a holistic approach to carbon fuels by tracking a complete transformation chain from fossil fuel sources to the fuel's end-use efficiency, to CCS, and, finally, to CO<sub>2</sub> industrial utilization. This approach allows comparison of different technological options from a "cradle-to-grave" viewpoint, thus providing better understanding of the challenges of transition from carbon-intensive to low-to-zero-carbon technologies. Being aware of the complexity and still-unknown factors behind climate change science, and taking into consideration the divergence of opinions and viewpoints on the role of nuclear energy, carbon storage, and geoengineering, the author tried to present a balanced view of the subject providing a podium to both sides of the debate.

This book is intended for a broad readership. Newcomers and nonexperts may find it a thorough introduction to the field of decarbonization of fossil fuels and CO<sub>2</sub> technologies (to help them, excessive technical details and jargon are mostly avoided in this book). At the same time, the book presents a large amount of up-to-date technical information and analysis that experts may find useful in their work. In general, the book will be handy to all scientists, engineers, and students working and studying in practically all areas of energy technology and alternative energy sources and fuels, and it will be a good supplement to textbooks on environmental technology, CCS, renewable energy sources, and alternative fuels.

This sourcebook provides a comprehensive overview of decarbonization and CO<sub>2</sub> utilization technologies that will play an increasingly important role in the near-to-mid term future in response to the ecological challenges of the carbon-intensive economy. It tries to answer a simple but vital question: will we be able to continue to rely on carbon fuels and live in harmony with the environment against a backdrop of an ever-growing demand for energy? The author hopes this book will contribute to an improved understanding and appreciation of the unique role carbon fuels and CO<sub>2</sub> play in today's life and will do so in the decarbonized energy future. The author also hopes this book will help the readers recognize the scope of problems and available options in order to make educated choices and set priorities with regard to adjusting to new realities of the carbon-constrained world.

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