Preface

Membranes are part of our daily life and exist as long as the first cells exist. Without membrane compartmentalization, there would be no cells and therefore no evolution from the simple aggregation of genetic materials such as that of viruses, which are not able to live autonomously. The preparation of synthetic membranes and their use in a broad range of applications are a more recent development, which cover the past 60 years. The seminal discovery that transformed membrane separation from a laboratory to an industrial process was the development in the early 1960s of the Loeb-Sourirajan process for making defect-free, high-flux, anisotropic reverse osmosis membranes [1]. The key property that is exploited is the ability of a membrane to control the permeation rate of a species through the membrane. In separation applications, the goal is to allow one component of a mixture to permeate freely, while hindering permeation of other components. Today, membranes are used not only to produce potable water from the sea, but also to clean industrial effluents minimizing environmental problems, to recover valuable compounds, to concentrate, purify, fractionate macromolecular mixtures in the food and drug industries, and to separate gases and vapors. Polymer membranes were commercialized to selectively remove H_2 from mixtures with larger molecules (N_2, CH_4, etc.), O_2 from air, natural gas upgrading. Methane is the main component of natural gas, which needs to be upgraded before its distribution in the pipeline. Natural gas upgrading via membrane gas separation offers many advantages compared to other more expensive and more footprint technologies such as amine absorption if the research efforts will result in high-performance membranes (selective and plasticization-resistant). Methane can be used as an energy carrier (secondary energy source) for all primary renewable energy sources just like hydrogen, but it is easier and safer to use, store, and transport than hydrogen. So, there is no need to wait for a possible hydrogen economy: Methane already has a large share of global energy consumption and its infrastructure is widespread. In the fields of energy extraction and storage, synthetic membranes are the key components of pressure-retarded osmosis (PRO) and reverse electrodialysis (RED), the two membrane technologies used to extract the blue energy (known also as osmotic power); membranes are one of the fundamental parts of redox flow batteries (RFBs), which—thanks to their distinguishing feature that energy and power can be scaled separately—are one of the more promising electrochemical energy storage technologies, in particular for the large-scale energy storage.

The purpose of this book is to provide a reasonably comprehensive overview of membranes for energy applications such as PRO, RED, and other energy-related applications such as membrane gas separation. The membranes used in these applications differ widely in their structures and function and the way they are operated. So, for any membrane application described in this book, before to focus on the membrane used, a detailed description of the key theoretical points of the process has been given as well as a broad number of relevant references, more than 200 references for each membrane application, to study in depth the topic. To make useful membranes, you have to understand the process.

This book is organized into six chapters, beginning with the overview, first chapter, which provides a short introduction to the fundamentals of the terminology used (difference between nanostructured and nano-enhanced membranes) and a rapid overview of membrane morphologies, configurations, transport, and modules. In the next two chapters of this book, the basic principles of PRO and RED have been described with some details as well as the characteristics required for high-performance membranes in these processes. A particular attention has been devoted to the membrane design and engineering, possible only when the membrane process is well understood. The following two chapters are on new polymer-based membranes for gas separation, in particular natural gas upgrading: on nanostructured, high free-volume polymer (Chapter 4), and nano-enhanced, mixed matrix (Chapter 5) membranes. The final chapter is dedicated to RFBs. A careful description of this interesting electrochemical energy storage is given to make the readers aware of the need for a holistic, not-disconnected approach between material science and process engineering to understand the characteristics required by a membrane which actually works.

This book is intended to be a research tool in which the most important insights in nano-enhanced and nanostructured membranes for PRO, RED, natural gas upgrading, and RFBs can easily be found. Thus, this book is directed to industrial, researchers, engineers, technicians, academics, and students of specialized courses. The most important goal is to bring new

insights into one of the most hot topic fields in materials science and engineering, i.e., nanostructured and nano-enhanced membranes for energy applications, and to make them available to those that need them.

The author hopes this book will provide a literature reference for the most demanding aspects of nanostructured and nano-enhanced membranes not only for the applications mentioned above and bring to the interested community a valuable publication to advance further developments in the field.

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Reference

[1] Loeb S, Sourirajan S. Sea water demineralization by means of an osmotic membrane. In: Saline water conversion-II. Advances in Chemistry Series Number 28. Washington, DC: American Chemical Society; 1963. p. 117–32.