Preface

This book provides an extensive overview of current thinking on applications, materials issues, and scale-up considerations related to dense oxygen and hydrogen transport membranes. For a broad outlook, international contributions have been obtained from researchers in academia, industry and national laboratories. Readers new to the field should find ample information on membrane fundamentals. Advanced researchers should find many previously unpublished concepts and research results to help forward their work. Readers will be aided by the large number of references to the membrane literature and especially by the extensive references to the patent literature, which reflect the potential commercial applications of membranes.

As this book goes to press, the world is once again concerned with dwindling supplies of natural gas and petroleum. Many nations are seeking more efficient means of utilizing the remaining carbon-based resources and investigating the production of alternative synthetic fuels. They are also concerned about rising CO₂ levels and their possible effect on climate, and about other pollutants originating from combustion. Membranes offer possible means of mitigating these problems.

Much energy from combustion has been wasted by the needless heating and handling of atmospheric nitrogen. In electric power plants which are dependent upon coal or natural gas, it has already (2005) been demonstrated that greater efficiencies are achieved by utilizing IGCC (Integrated Gasification Combined Cycle) power plants incorporating cryogenic oxygen separation. Even greater efficiencies could be achieved if oxygen transport membranes were commercially available.

In the area of alternative fuels, one starting point is the reaction of coal, natural gas or biomass with oxygen (and steam) to form synthesis gas. Oxygen transport membranes can play a major role in the more efficient production of synthesis gas, and hydrogen transport membranes can be used to extract pure hydrogen as a fuel or to adjust levels of hydrogen in the syngas mixture. The hydrogen and carbon monoxide of synthesis gas is used to produce clean-burning oxygenated liquid fuels including methanol and ethanol, as well as sulfur-free Fischer–Tropsch liquids.
As this book goes to press, some estimates predict that the world will require one new electric power plant *every three days* for the period 2005–2035. The addition of approximately 3650 new electric power plants worldwide over the next 30 years will greatly aggravate problems associated with atmospheric CO₂ – assuming that coal will be utilized in larger quantities. One proposed solution is sequestration of CO₂. This might be accomplished by gasifying coal with pure oxygen (and steam) at pressures of 30–70 bar to form synthesis gas. The CO in the synthesis gas could then be further reacted with steam in water-gas shift reactors to form a gas mixture containing predominantly H₂, CO₂ and steam. If membranes were commercially available to extract and purify hydrogen from water-gas shift mixtures while retaining CO₂ at high pressure and concentration, the pure hydrogen could be used as a nonpolluting fuel in fuel cells or hydrogen-powered turbine engines, and, by avoiding most of the compression costs, the CO₂ could be efficiently sequestered. Hydrogen transport membranes may play critical roles in pre-combustion de-carbonization of carbonaceous fuels. Hydrogen transport membranes may also play an essential role in the ultrapurification of hydrogen required for fuel cells.

Although the topic of this book is limited to dense inorganic membranes, some knowledge of biological membranes might be sought as a source of inspiration for what yet might be possible with synthetic membranes. It should be appreciated that human lungs efficiently separate oxygen from nitrogen at body temperature. The membranes of chloroplasts in green plants separate CO₂ from air and allow effective sequestration of CO₂ in glucose, starch, cellulose and in a myriad other organic materials. Membranes in the mitochondria are essential for oxidation and efficient use of chemical energy – at body temperature. The enzyme-like proteins spanning the membranes of cells in the human brain, stereoselectively adsorb and transport glucose to the exclusion of most other molecules. Other membrane proteins with enzyme-like stereospecific sites have evolved to selectively adsorb and transport complex organic molecules into and out of living cells while excluding the transport of smaller, simpler molecules. The membranes of our digestive systems allow the secretion of large enzymes, while limiting the passage of small molecules. It is noteworthy that biologists theorize that, before life could evolve, it was necessary for membranes to exist in pre-biotic colloidal masses, and that the present life on earth could not exist without membranes. Inspiration derived from biological membranes may drive the development of new membrane technologies.

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