Green and Sustainable Chemistry and Engineering

A Practical Design Approach

Concepción Jiménez-González and David J. C. Constable

Second Edition

with website

WILEY

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A Practical Design Approach

SECOND EDITION

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ABOUT THE AUTHORS

Dr. Concepción "Conchita" Jiménez-González is currently Vice President, Head of R&D Environment, Health, Safety, and Sustainability at GSK, where she has held various roles of increasing responsibility throughout 20+ years. In her current role, she is responsible for embedding a safety culture and sustainability principles into the Research and Development operations at GSK. She is an adjunct professor at North Carolina State University (NCSU) teaching a Green Chemical Engineering class. She has been an active contributor in the fields of sustainability, life cycle assessment, green engineering, material selection, green technologies, and energy optimization, much of this is a result of her GSK's work. Prior to joining GSK, she was program manager, full-time researcher, and professor at the Environmental Quality Center and the Department of Chemical Engineering of Tecnológico de Monterrey (previously ITESM, México). She was also a visiting researcher at Pfizer in Groton, CT, a visiting faculty in the Environmental Engineering graduate program at the Saltillo Institute of Technology, Mexico, and a consultant in Environmental Engineering. She received her B.S. in Chemical and Industrial Engineering from the Chihuahua Institute of Technology, Mexico; M.Sc. in Environmental Engineering from the Monterrey Institute of Technology and Superior Education (ITESM), Monterrey, Mexico; PhD in Chemical Engineering from NCSU, and MBA also from NCSU. Following the Spanish tradition, she is also known as Conchita.

Dr. David J. Chichester-Constable is currently retired. From January 2013 to December 2022, David worked for the American Chemical Society as Director and Science Director of the Green Chemistry Institute. In this role, David contributed to advancing the science and practice of Sustainable and Green Chemistry and Engineering. Prior to joining the ACS, David served as Vice President of Energy, Environment, Safety and Health at Lockheed Martin for three years. Before joining Lockheed Martin, he worked in GlaxoSmithKline for over 17 years in various positions of increasing responsibility in environmental fate and effects testing, product stewardship, green chemistry and technology, life cycle inventory/assessment, and sustainable development. He also spent 6 ½ years at ICI Americas, heading a laboratory that developed sampling and analytical methods for environmental and human exposure studies. David holds a B.S. in Environmental Studies, Air and Water Pollution from the Slippery Rock University, PA, and a PhD in Chemistry from the University of Connecticut. He has taught a course in Green Chemistry at Rowan University, NJ, and has published in various areas such as analytical chemistry, environmental fate and effects, material selection, and green chemistry and technology and sustainability.

PREFACE

Over the past three decades, interest in and understanding of Sustainability, Green Chemistry, and Green Engineering has increased steadily beyond academia and into the business world and is slowly evolving toward greater consideration of sustainability. Industries with different sectors of the economy have made concerted efforts to embed these concepts to a greater or lesser degree into their operations, but progress has not been as fast as we think and is needed to address current and upcoming sustainability challenges. Over 15 years ago, given our experience with green chemistry and green engineering in the pharmaceutical industry, we were approached by the publishers to edit a book on green chemistry in the pharmaceutical industry. While this was a worthy proposal, we felt we had a greater opportunity and a worthier endeavor to produce a book that would more fully integrate *Green and Sustainable Chemistry and Engineering* into the academic curricula and that, at the same time, could serve as a practical reference to chemists and engineers in the workplace.

Green and Sustainable Chemistry and Engineering ideas and concepts are still not being sufficiently ingrained into traditional chemistry and engineering curricula to the extent that is necessary for a world that has continued toward exceeding critical boundary conditions for planetary well-being. This is especially true for chemistry, although classes and even majors in these topics have become increasingly common. However, most classes in green and sustainable chemistry are typically taught from an environmental chemistry perspective or a synthetic organic chemistry perspective, with neither approach addressing issues of manufacturing or manufacturability of products. The consequence of this is that many chemists have no idea how to create new substances that are anywhere close to being sustainable from a systems and life cycle perspective. Green Engineering classes, on the other hand, tend to emphasize issues related to manufacturing, but do not have a sufficient treatment of reaction and process chemistry. These disciplines therefore still seem to be disconnected. This lack of integration between chemistry, engineering, and other key disciplines has been one of the main challenges we have had within the industrial workplace and in previous academic experiences.

As a consequence of these experiences, we decided to write this book as an attempt to bridge the great divide between bench chemistry, process design, engineering, environment, health, safety, systems thinking, and life cycle considerations. We felt that a systems-oriented and integrated approach was needed to evolve Green Chemistry and Engineering as disciplines in the broader context of sustainability. To achieve this, we have organized the book into five main sections.

- Part I. Green and Sustainable Chemistry and Engineering in the Movement Toward Sustainability. Chapters 1–5 set the broader context of sustainability, highlighting the key role that green and sustainable chemistry and engineering have in moving society toward the adoption of more sustainable practices in providing key items of commerce.
- Part II. The Beginning: Designing Greener, Safer, More Sustainable Chemical Syntheses. Chapters 6–9 address the key components of chemistry that will contribute to the achievement of more sustainable chemical reactions and reaction pathways. They also provide an approach to materials selection that promotes the overall sustainability of a chemical synthesis without diminishing the efficiency of the chemistry or associated chemical process.
- Part III. From the Flask to the Plant: Designing Greener, Safer, More Sustainable Manufacturing Processes. Chapters 10–15 provide those key engineering concepts that support the design of more sustainable chemical processes.
- Part IV. Expanding the Boundaries. Looking beyond our processes, Chapters 16–20 bring the life cycle thinking perspective by providing background and context for placing a particular chemical process in the broader chemical enterprise, including its impacts from raw materials extraction to recycle or reuse, or end-of-life considerations.
- Part V. What Lies Ahead. Beyond the chemical processing technology of today or delivering tomorrow's products more sustainably. Finally, Chapters 21–23 provide some indication of trends in chemical processing that may lead us towards more sustainable practices.

To help provide a practical approach, we have included examples and exercises that will help the student or practitioner to understand these concepts as applied to the industrial setting and to use the material in direct and indirect applications. The exercises are intended to make the book suitable for both self-study or as a textbook, and most exercises are derived from our professional experiences.

This book is an outgrowth of our experience in applied and fundamental research, consulting, teaching, and corporate work on the areas of green chemistry, green engineering, and sustainability. It is primarily intended for graduate and senior-level courses in Chemistry and Chemical Engineering, although we hope that chemists and engineers working in manufacturing, research, and development; especially the fine chemicals and pharmaceutical areas will find this book to be a useful reference for process design and re-engineering. We hope that this will provide enough balance between the academic needs and the practical industrial application of an integrated approach between green and sustainable chemistry and engineering.

Concepción "Conchita" Jiménez-González
and David J. C. Constable
January 2024

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ABOUT THE COMPANION WEBSITE

This book is accompanied by a companion website:

www.wiley.com/go/Green_and_Sustainable_Chemistry_and_Engineering/2e

The website includes:

- Solutions manual
- Figures in PPT

PART I

GREEN AND SUSTAINABLE CHEMISTRY AND ENGINEERING IN THE MOVEMENT TOWARD SUSTAINABILITY