Horizons in Sustainable Industrial Chemistry and Catalysis – An Introduction

Horizons in Sustainable Industrial Chemistry and Catalysis, Volume 178 of the *Studies in Surface Science and Catalysis* series, aims at giving a comprehensive picture of recent developments in terms of sustainable industrial processes as well as the connected catalytic needs and opportunities to develop these novel routes. In fact, driven from competitiveness in a changing economic world with an increasing transition to renewable energy, chemical and refinery production are in a major transition phase to go beyond fossil fuels (as main raw materials and energy source) and to increase sustainability [1-3]. It is thus necessary to rethink chemical and refinery production methodologies, with consequent need of new catalysis approaches. In fact, due to energy-chemistry nexus, and the changes in refinery associated to energy transition, there is the need to reconsider the actual (nearly exclusive) use of fossil resources for chemical production. In parallel, a change in the business model for chemical production is emerging: from the actual one (based on large plants and centralized production, with worldwide import of raw materials) to a distributed production model, based on the use of local resources (renewable energy and alternative C-sources). The challenge is to integrate the use of biomass sources for chemical production [4], which has largely dominated discussion in the last decade, to the use of C-sources alternative to fossil one (waste, CO_2) in combination with the use of renewable sources of energy (electrified chemical production and beyond, such as artificial leaf) [5-8].

This book will address these questions by analysing recent developments in the area of catalytic processes and materials to showcase new opportunities and challenges deriving from this changing scenario in chemical and energy production. This is the motivation of the word “Horizons” in the title, and the emphasis given in the title to the concept of “Sustainable Industrial Chemistry”.

In fact, the background for this book is the *European Doctorate in Sustainable Industrial Chemistry* (SINCHEM) [9] financed from EU inside the ERASMUS Mundus PROGRAMME. SINCHEM is an international joint Doctoral School in Sustainable Industrial Chemistry offered by a consortium of 33 partner institutions (7 full partners and 26 associated members). Strong industrial links to major companies in the field are a key part of SINCHEM. The three Editors of this book involve i) the project coordinator (S. Albonetti) and ii) the local coordinators for the Univ. of Messina (S. Perathoner) and Univ. Lyon-CNRS-CPE Lyon (E. A. Quadrelli) in the SINCHEM project.

Different chapters of the book are prepared by selected PhD students of this European Doctorate in coordination with their senior supervisors. The chapters have been selected to give a panorama of recent developments in terms of sustainable industrial processes, and of the catalysis needs and opportunities to develop these novel routes. Each chapter will thus present a first general part providing a state of the art in the field, and a second part where a series of specific aspects and examples will be discussed.

The book is thus targeted at young researchers that like to better identify the new opportunities for research offered from this changing scenario. Being written in collaboration between young researchers

strongly involved in the specific sub-area (the main area of their PhD thesis) and senior scientists, the book will try to catch both the enthusiasm of the young researchers and the experience of the senior ones.

It is thus aimed to be a novel book, not only for the challenging topic, but also for the style of writing. In fact, today a book should offer something different from being just a collection of reviews, as may be found in literature. A book should report not only a comprehensive overview of a specific topic (in this case, the novel directions of development in catalysis to address the changing energy and chemical production scenario), but also a different way to overview the specific topics, from one side being more critical to evidence the limit of current activities, and from the other side providing also more practical indications. Both these aspects are typically original with respect to most of literature reviews. The proposed book is thus different from other available and is a unique opportunity for young and senior researchers, as well science managers, to identify new opportunities for research that will help us transition to a low carbon and sustainable energy and chemical production. Users will find an integrated view of the new possibilities in this area that unleashes new possibilities in energy and chemistry.

Key features of the book include to:

- Combine an analysis of each scenario, the state-of-the art, and specific examples to help users better to understand needs, opportunities, gaps and challenges
- Offer an integrated view of new catalytic technologies that are needed for future use
- Present an interdisciplinary approach that combine a broad expertise
- Bring together experts in the area of sustainable industrial chemistry

The book is organized in four sections, each with a short preface and containing from three to seven chapters, for a total of 19 chapters. The four sections are the following:

1. *Solar-driven energy and chemical production*, where the following aspects are discussed: i) the production of solar fuels using CO_2, ii) the electro-catalytic activation of N_2, iii) the photo-production of ammonia, iv) the visible-light driven catalysts for water oxidation in relation especially to solar fuel biorefineries, v) the catalytic methanation of CO_2 to store renewable energy, vi) the catalytic synthesis of carboxylic acids using CO_2 as a building block and vii) the conversion of CO_2 to organic carbonate.
2. *Bio-based processes and beyond*, where the following aspects are discussed: i) the emerging directions in biomass valorisation deriving from pattern identification in literature, ii) the production of glycols from lingo-cellulosic biomass, iii) the use of hydrogen transfer reaction for the valorisation of biomass-derived building blocks, iv) the interest in terpenes as a valuable family of compounds for the production of fine chemicals, v) the possibilities offered from the development of upgraded bio-oil and vi) the catalytic production of functional aromatic compounds from lignin.
3. *Advanced sustainable chemical processes and catalysts for environment protection*, with aspects discussed including the development of i) spinel mixed oxides for chemical-loop reforming, ii) structured

catalysts based on open-cell metallic foams, and iii) new catalysts for the simultaneous soot and NOx abatement in light-duty diesel engine vehicle application.

4. *New advanced catalytic materials*, covering aspects such as i) alginate as a versatile biopolymer to produce catalysts and advanced materials, ii) the novel routes to prepare silica-supported Pt and Pd catalysts with hierarchical porosity, and iii) the development of well-defined nanoparticles for model studies in sustainable industrial chemistry.

For each of these sections, a series of *key horizon* aspects were identified, with one to three book chapters discussing specific relevant items. The general book structure is shown below.

BOOK	SECTIONS	KEY HORIZON (KH)	CHAPTERS
Horizons in Sustainable Industrial Chemistry and Catalysis	1. Solar-driven energy and chemical production	KH1: Green electrons & REN storage	1, 4, 5
		KH2: More REN-driven processes in chemical industry	2, 3
		KH3: CO2-based processes	6, 7
	2. Bio-based processes and beyond	KH4: Green bio-based materials	8, 9
		KH5: Develop new green catalytic routes for biomass transformation	10, 11
		KH6: New generation of sustainable processes for producing bio-based fuels and chemicals	12, 13
	3 - Advanced sustainable chemical processes and catalysts for environment protection	KH7: New catalytic materials and processes	14, 15
		KH8: Development of multifunctional catalysts for environmental protection	16
	4. New advanced catalytic materials	KH9: Use of bio-resources to develop advanced catalysts and functional materials	17
		KH10: Controlling hierarchical porosity and nanoparticles characteristics	18, 19

The book, through its 19 chapters plus these general introductions and more specific introductions to each section, gives thus a glimpse about novel catalysts and catalytic routes to address the transition to a low carbon society and sustainable chemical/energy industrial production. On the background the "Science and Technology Roadmap on Catalysis", prepared by one of the editors of this book (S. Perathoner) in the frame of the activities of the the European Cluster on Catalysis [10] and with some of the elements discussed in ref.s [2,3]. The roadmap addresses the possible scenario (from sustainability and competitiveness

perspectives) for the production of chemicals and for chemical energy conversion, the latter playing an important role in fostering the transition to renewable energy sources. Three "grand-challenges for catalysis" are discussed: i) catalysis to address the evolving energy and chemical scenario; ii) catalysis for a cleaner and sustainable future; and iii) catalysis complexity, an aspect divided in three sub-topics: a) advanced design of novel catalysts, b) understanding catalysts from molecular to material scale, and c) expanding catalysis concepts. Several of the elements discussed in this roadmap are analysed in the various Chapters of the book.

In conclusion, we hope with this book to provide the reader with an updated view of driving elements in terms of new capabilities for understanding catalysis and precise synthesis, and of new catalysis requirements to address the changing scenario in chemical production. The book is multifaceted, to offer both young and senior researchers as well as managers in companies and decision makers the understanding of the opportunities and difficulties in a fast changing scenario for both chemical production and energy. It thus combines foundational and applied aspects, together with some elements of the new business opportunities offered from the changing production scenario, and to understand the new possibilities to move to a low carbon society. The book is written for chemists, chemical engineers in academia and corporate research.

References

1. P Lanzafame, S Abate, C Ampelli, C Genovese, R Passalacqua, G Centi, S Perathoner, Beyond Solar Fuels: Renewable Energy-Driven Chemistry, *ChemSusChem* 2017, 10 (22), 4409-4419.
2. S Perathoner, S Gross, EJM Hensen, H Wessel, H Chraye, G Centi, Looking at the Future of Chemical Production through the European Roadmap on Science and Technology of Catalysis the EU Effort for a Long-term Vision, *ChemCatChem* 2017, 9 (6), 904-909.
3. P Lanzafame, S Perathoner, G Centi, S Gross, EJM Hensen, Grand challenges for catalysis in the Science and Technology Roadmap on Catalysis for Europe: moving ahead for a sustainable future, *Catalysis Science & Techn.* 2017, 7 (22), 5182-5194
4. F Cavani, S Albonetti, F Basile, A Gandini, Chemicals and Fuels from Bio-Based Building Blocks, J. Wiley & Sons 2016, ISBN:9783527338979
5. G Centi, EA Quadrelli, S Perathoner, Catalysis for CO_2 conversion: a key technology for rapid introduction of renewable energy in the value chain of chemical industries, *Energy & Env. Science* 2013, 6 (6), 1711-1731
6. W Leitner, EA Quadrelli, R Schlögl, Harvesting renewable energy with chemistry, Green Chem. 2017, 19 (10), 2307-2308
7. EA Quadrelli, 25 years of energy and green chemistry: saving, storing, distributing and using energy responsibly, *Green Chem*. 2016, 18 (2), 328-330

8. P Lanzafame, G Centi, S Perathoner, Catalysis for biomass and CO_2 use through solar energy: opening new scenarios for a sustainable and low-carbon chemical production, *Chem. Soc. Rev.* 2014, 43, 7562-7580
9. Web site of SINCHEM: The European Doctoral Programme on Sustainable Industrial Chemistry http://www.sinchem.eu
10. S. Perathoner, G. Centi, Science and Technology Roadmap on Catalysis for Europe. A Path to Create a Sustainable Future, ERIC aisbl Pub.: 2016. ISBN 979-12-200-1453-3
11. European Cluster of Catalysis: www.catalysiscluster.eu

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