

Kenneth N. Timmis

Handbook of Hydrocarbon and Lipid Microbiology

With 712 Figures* and 277 Tables

 Springer

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Preface

“Water is life!” All active cellular systems require water as the principal medium and solvent of their metabolic and ecophysiological activities. Hydrophobic compounds and structures, which tend to exclude water, though providing *inter alia* excellent sources of energy and a means of biological compartmentalization, present problems of cellular handling, poor bioavailability and, in some cases, toxicity. Microbes both synthesize and exploit a vast range of hydrophobic organics, especially petroleum oil hydrocarbons and industrial pollutants, and the underlying interactions not only have major consequences for the lifestyles of the microbes involved, but also for biogeochemistry, climate change, environmental pollution, human health and a range of biotechnological applications. In this Handbook we attempt to cover the exceptional range of cellular, population and community activities of microbes interacting with the major hydrophobic organics found in the biosphere and to encapsulate the consequences of such interactions for the health and disease of microbes, higher organisms and the environment, as well as the beneficial applications that have been or can be developed therefrom. In order to achieve this goal with a text of reasonable length, it was decided to conceive a Handbook consisting of many short chapters dealing with their topics in a relatively superficial manner, while citing original references that document the principal advances described, rather than of long chapters providing detailed, comprehensive coverage of individual topics, some of which already exist in other excellent texts.

Although this Handbook started with a game plan, a framework of topics to be covered, it evolved continuously throughout the chapter recruitment period, as more and more new facets of microbe:hydrocarbon/lipid interactions became apparent, many of which were entirely new at the time of recruitment, which underscores both the explosion of highly original research in the area, and the continuous discovery of new activities and consequences of microbial activities at hydrophobic:hydrophilic substance interfaces. Eventually, in order to move the Handbook into production (and to avoid a revolution among authors who had provided chapters on time), we reluctantly had to stop adding new topics. During the process of literature review, chapter conception, text formulation, and chapter reviewing and editing, authors and editors alike became exposed to exciting new information that, in some cases, sharply increased creativity. This is of course a major motivation for participation in such an effort.

As far as we are aware, this Handbook breaks new ground in attempting to deal generically with microbial interactions with major hydrophobic organics in the biosphere, that is, with the fundamental problem of hydrophobicity for water-based cellular systems, and in exploring generically the wide range of consequences for (wo)mankind of such interactions. Volume 1 sets the scene for hydrophobic microbiology with introductory chapters that describe the main hydrophobic organic compounds in the biosphere, their diversity and physico-chemical characteristics, how they are formed, how they enter the biosphere (including via anthropogenic activities like mining, accidents and illegal dumping), and where in the biosphere

they are to be found. Subsequent chapters deal with the biogenesis of hydrophobic compounds and organelles - methane, other hydrocarbons, fatty acids, lipids, oils and wax esters - their biochemistry, genetics, genomics, microbiology and ecophysiology. The second Volume constitutes a sequel to the production of hydrophobic compounds, and deals with their consumption. It not only outlines the biochemistry, genetics and ecology of utilization, but also describes the physiological problems of interactions with such compounds, like poor bioavailability, uptake, toxicity and problems of an acetyl-CoA-centric metabolism. Following this framework of the generic biology underlying microbe:oil interactions, Volume 3 provides up-to-date descriptions of the biological players in these interactions: the hydrocarbon-utilizing microbes themselves and the microbial communities in which they function. With the fundamentals of hydrocarbon and lipid production and consumption by microbes documented, Volume 4 is dedicated to the wide range of consequences of these interactions. These include hydrocarbon biodegradation and bioremediation, biomonitoring, fuel production, chemicals production, global consequences, and consequences for the health and disease of higher organisms. Volume 4 ends with a brief selection of author predictions on the future of “greasy microbiology”. To complete the Handbook, Volume 5 provides a comprehensive set of methods and protocols for research in greasy microbiology. This is to our knowledge the first and only, much needed collection of state-of-the-art protocols for research in this topic and will, we anticipate, become a major experimental resource for the community that facilitates and accelerates important advances. Volume 5 ends with an Annex of literature and Web resources pertinent to the topic of hydrocarbon and lipid microbiology.

In addition to dealing with the generic biology of microbial interactions with hydrophobic substances, the Handbook comprises a unique combination of topic overviews that includes:

- most up-to-date listing and description of hydrocarbon-producing and -consuming microbes
- ecophysiology of hydrocarbon-producing and -consuming microbial communities in the diverse hydrocarbon-containing habitats of the biosphere
- global overview of key metabolic routes to and from central metabolism from and to hydrocarbons, lipids and hydrophobic storage products.
- enzymology/catalytic mechanisms underlying HC-processing in aerobic and anaerobic environments
- genetics of relevant pathways and genomics of key model strains
- stresses imposed by hydrocarbons, physiological responses and tolerance mechanisms
- hydrocarbon microbiology and global warming
- the range of applications of hydrocarbon-metabolizing microbes
- alternative energy sources
- oleochemical biotechnology
- enzyme and metabolic engineering; systems biology of industrial processes
- hydrocarbons, lipids and microbial infections of humans, animals and plants

In selecting topics to be covered, and the chapters and authors needed to do these topics justice, we were supported by a blue-blooded Scientific Advisory Board of leading researchers in the various sectors of “greasy” microbiology. These experts not only helped frame the contents of the Handbook and fingered potential authors of chapters, but also in most cases contributed one or more chapters and carried a considerable burden of the reviewing of chapters by others. Following a gentle but firm suggestion from my very good friend, Victor de Lorenzo, that I delegate part of the editorial load, a subgroup of the SAB subsequently accepted

to take on editorial responsibilities, resulting in the Handbook acquiring three Section Editors: Terry McGenity, for taxonomic sections, Jan Roelof van der Meer, for the methods sections, and Victor de Lorenzo, for genetic/genomic sections. I am most grateful to Victor for his advice, and to him, Terry and Jan Roelof for the super efforts they invested in the Handbook. They were fun people with which to work on this project.

In addition to the SAB, a number of contributors to the Handbook provided enthusiastic support over and above the call of duty, in terms of advice, author and topic suggestions, and offers to cover topics lacking authors. These include, in no particular order, Heinz Wilkes, Otto Geiger, Karin Athenstaedt, Dietmar Pieper, Hauke Harms, Lukas Wick, Ibrahim Banat, Becky Parales, Herman Heipieper, Julia Foght, Sylvie Le Borne, Antje Boetius, Charles Greer, Eugene Rosenberg, Manolo Ferrer, Karl-Erich Jäger, Monica Bassas, Sagrario Arias, Ann Wood, and the Facelt consortium.

Finally, I wish to express my undying gratitude to the people who not only made this major work possible, but also made it such a satisfying project:

- the Section Editors, Victor, Terry and Jan Roelof, who enthusiastically dedicated much time, effort and creative energy to the project, including the writing of (additional) chapters they thought were important that failed to be delivered by authors who had initially accepted,
- the SAB, who supported and advised during the conception and realization of the Handbook, and reviewed many of the manuscripts,
- some special people - Don Kelly and Ann Wood, Willy Verstraete, Fritz Widdel, Sylvie Le Borne, Roger Prince, Dietmar Pieper, Misha Yakimov and Colin Murrell - who became truly infected with the excitement of the project and committed themselves to so many chapters, some proposed to them, some they proposed themselves, and whose enthusiasm raised the fun level of the project to unanticipated heights,
- the folks at Springer, especially Christina Eckey, who initiated the whole thing, **Lydia Müller, Simone Giesler and Sylvia Blago, who were the production interface with authors and editors and did all the manuscript processing**, and Dieter Czeschlik, the senior figure in the publication of this tome. I have had a number of editorial experiences during a long career, but this was certainly the most enjoyable, as a result of the enthusiasm, responsiveness, friendliness and sense of humour of these professionals.
- and, finally, my long term wife and partner, Joan, and our son, James, who also sacrificed family quality time in the cause of the Handbook and, in the case of Joan, spent long hours on the internet seeking and re-seeking authors' affiliations and e-mail addresses, and learning that the web is as chaotic as the Editor of this Handbook.

Thank you all for your exceptional efforts, enthusiasm and support in creating a work summarizing exciting discoveries and impressive research achievements in hydrocarbon microbiology that we all hope will focus the spotlight on an exciting group of interconnected biological research topics that have major implications for society, its energy supplies, chemicals and pharma, nutrition, health and disease, the environment, global warming, and their future development, and that will stimulate and inspire new research efforts and the exploration of new directions.

Kenneth Timmis
HZI, Braunschweig,
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About the Editor



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Kenneth Timmis studied microbiology and obtained his Ph.D. at Bristol University. He undertook post-doctoral training at the Ruhr-University Bochum, Yale and Stanford, at the latter two as a Fellow of the Helen Hay Whitney Foundation. He was then appointed Head of an Independent Research Group at the Max Planck Institute for Molecular Genetics in Berlin, then Professor of Biochemistry in the University of Geneva, Faculty of Medicine. Thereafter, for almost 20 years, he was Director of the Division of Microbiology at the National Research Centre for Biotechnology (GBF)/now the Helmholtz Centre for Infection Research (HZI). He is currently Head of the Environmental Microbiology Laboratory at the HZI and Professor of Microbiology at the Technical University, Braunschweig. Kenneth Timmis has worked for more than 30 years in the area of environmental microbiology and biotechnology, has published over 400 peer-reviewed original research papers in international journals, and is an ISI Highly Cited Microbiology-100 researcher. His group has worked for many years, *inter alia*, on the biodegradation of oil hydrocarbons, especially the genetics and regulation of toluene degradation, pioneered the topic of experimental evolution of novel catabolic activities, discovered the new group of marine hydrocarbonoclastic bacteria, and initiated genome sequencing projects on bacteria that are paradigms of microbes that degrade organic compounds (*Pseudomonas putida* and *Alcanivorax borkumensis*). He is Fellow of the Royal Society, Member of the EMBO, Fellow of the American Academy of Microbiology, Member of the European Academy of Microbiology, Recipient of the Erwin Schrödinger Prize, and Scientific Advisory Board Member of leading research institutes. He founded the journals Environmental Microbiology and Microbial Biotechnology.



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Terry McGenity is a senior lecturer at the University of Essex, UK. His PhD, investigating the microbial ecology of ancient salt deposits (University of Leicester), was followed by postdoctoral positions at the Japan Marine Science and Technology Centre (JAMSTEC, Yokosuka) and the Postgraduate Research Institute for Sedimentology (University of Reading). He worked as a postdoc with Ken Timmis at the University of Essex, where he was inspired to investigate microbial interactions with oil at multiple scales, from communities to cells, and as both a source of food and stress. He has broad interests in microbial ecology and diversity, particularly with respect to carbon cycling, and is driven to better understand how microbes cope with, or flourish in, hypersaline, desiccated and poly-extreme environments.



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Jan Roelof van der Meer is Professor of Environmental Microbiology at the University of Lausanne, Switzerland. The main focus of his current research is the evolutionary adaptation of bacteria to hydrocarbon pollution, and the use of bacteria as microscale sensors for hydrocarbon pollution and bioavailability. He studied Environmental Sciences at, and received his Ph.D. in 1992 from, the University of Wageningen in The Netherlands. From 1992 to 2003 he worked as Group Leader at the Swiss Federal Institute of Aquatic Sciences (EAWAG) near Zürich. He is currently coordinating the sixth Framework STREP Project FaceIt, and the seventh Framework Project BACSIN, which assembled key groups in Europe to work on pollution effects and biodegradation. One of the goals of the FaceIt project, in which Victor de Lorenzo, Terry McGenity and Ken Timmis were also involved, was to assemble and publish a collection of methods and strategies for laboratory and field work in hydrocarbon microbiology. This aim ultimately merged with the concept of the Handbook to produce Volume 5. We are very grateful for the invaluable help, time, energy, and expertise that the FaceIt project partners, along with the many other contributors, have invested in this volume.



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Victor de Lorenzo (Madrid, 1957) is currently Professor of Research at the Spanish National Centre for Biotechnology. Although he is a chemist by training, he developed an interest for Microbiology and Environmental Biotechnology. After his PhD in Madrid (1993, Autonomous University) and various postdoctoral positions in Paris (1984, Institut Pasteur), Berkeley (1985–1987, University of California), Geneva (1988, Centre Medical Universitaire), and Braunschweig (1989–1990, Gesellschaft für Biotechnologische Forschung), he decided to pursue the problem of environmental pollution, not only as a biotechnological challenge, but also as the source of fundamental questions in biology. These include the evolutionary emergence of catalytic functions and their regulatory proteins and networks, as well as the mechanisms behind the metabolic economy of cells under natural conditions. Since his postdoc with Ken Timmis in the GBF in the late 1980s, he developed a taste for the design of genetic tools that continues to this day. Many such tools are used by hundreds of laboratories around the world, and many others are in the pipeline for facilitating the application of synthetic biology to environmental questions.



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