

# Aqueous-Phase Organometallic Catalysis

Concepts and Applications

*Edited by*  
*Boy Cornils and Wolfgang A. Herrmann*

Second, Completely Revised and Enlarged Edition



WILEY-VCH Verlag GmbH & Co. KGaA



**Aqueous-Phase  
Organometallic Catalysis**

*Edited by  
Boy Cornils and Wolfgang A. Herrmann*

## ***Further Titles of Interest***

B. Cornils, W. A. Herrmann (Eds.)

### **Applied Homogeneous Catalysis with Organometallic Compounds**

Second, Completely Revised and Enlarged Edition

3 Volumes, 2002

ISBN 3-527-30434-7

B. Cornils, W. A. Herrmann, R. Schlögl, C.-H. Wong (Eds.)

### **Catalysis from A to Z**

Second, Completely Revised and Enlarged Edition

2003

ISBN 3-527-30373-1

A. de Meijere, F. Diederich (Eds.)

### **Metal-Catalyzed Cross-Coupling Reactions**

Second, Completely Revised and Enlarged Edition

2004

ISBN 3-527-30518-1

R. H. Grubbs (Ed.)

### **Handbook of Metathesis**

3 Volumes, 2003

ISBN 3-527-30616-1

# Aqueous-Phase Organometallic Catalysis

Concepts and Applications

*Edited by*  
*Boy Cornils and Wolfgang A. Herrmann*

Second, Completely Revised and Enlarged Edition



WILEY-VCH Verlag GmbH & Co. KGaA

#### **Editors**

**Prof. Dr. Boy Cornils**

Kirschgartenstraße 6  
65719 Hofheim  
Germany

**Prof. Dr. Dr. h.c. mult. Wolfgang A. Herrmann**

Anorganisch-Chemisches Institut  
der Technischen Universität München  
Lichtenbergstraße 4  
85747 Garching  
Germany

■ This book was carefully produced. Nevertheless, authors, editors, and publisher do not warrant the information contained therein to be free of errors. Readers are advised to keep in mind that statements, data illustrations, procedural details or other items may inadvertently be inaccurate.

**Library of Congress Card No: applied for**

A catalogue record for this book is available from the British Library.

**Bibliographic information published  
by Die Deutsche Bibliothek**

Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available in the Internet at <<http://dnb.ddb.de>>.

© 2004 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

All rights reserved (including those of translation into other languages). No part of this book may be reproduced in any form – by photoprinting, microfilm, or any other means – nor transmitted or translated into machine language without written permission from the publishers. Registered names, trademarks, etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

Printed in the Federal Republic of Germany

Printed on acid-free paper

**Typesetting, printing and binding**

Konrad Triltsch  
Print und digitale Medien GmbH  
Ochsenfurt-Hohstadt

**ISBN** 3-527-30712-5

## Preface to the Second Edition

Very recently, some colleagues noticed a statement in one of the monthly columns about the state-of-the-art that “in organic chemistry reactions employing the solvent water are still rare [1]” – which is true and untrue at the same time: certainly, water-based conversions are scarce compared to those in the great majority of other solvents. But whoever was sensitive enough to recognize the tremendous possibilities of aqueous-phase catalysis would never ignore the increasing number of publications concerning this field of activity, the progress which has taken place during recent years, and the breakthroughs which have been brought about following these activities.

So it is a great pleasure for us to announce the second edition of our book *Aqueous-Phase Organometallic Catalysis* – in such close proximity to the first edition in 1998. Responsible for this are on the one hand the dramatic successes of industrial realization: production figures are now close to 1 MM tons per year in various applications (with hydroformylations, at approximately 800 000 tpy, in a senior position). On the other hand, the long overdue in-depth occupation with the scientific basis, the exploratory work with the various possibilities of this “immobilization with the liquid support water”, and the exploitation of the immense variability of the method in chemical respects (regarding central atoms and ligands) create an atmosphere of overwhelming interest in this technique.

Thus the sections of this revised edition have been enlarged to different extents. For instance, in respect of the scientific fundamentals and taking into account that the role of water in organometallic conversions is not only purely as a solvent but as a strongly coordinative polar reagent. It contributes considerably to the formation of polar or ionic intermediates or to oxidative additions to lower-valent transition metal complexes (thus explaining the strong pH dependence of many aqueous-phase catalyzed reactions). The work on different central atoms of catalytically active complexes and the search for alternative, highly specialized ligands – including chiral ones – has extended considerably the scope of aqueous-phase organometallic catalysis together with knowledge about coordination catalysis.

The same is true for the application of water-soluble catalysts for quite a bunch of basic organometal-derived chemical reactions ranging from hydrogenations or

hydroformylations to more “exotic” applications such as water-based enantioselective Diels–Alder reactions or kinetic resolutions. It also includes improvements and alternative answers for the chemical reaction engineering of aqueous-phase catalyzed conversions.

Last but not least, the success of aqueous-phase catalysis has drawn the interest of the homogeneous-catalysis community to other biphasic possibilities such as organic/organic separations, fluorous phases, nonaqueous ionic liquids, supercritical solvents, amphiphilic compounds, or water-soluble, polymer-bound catalysts. As in the field of aqueous-phase catalysis, the first textbooks on these developments have been published, not to mention Joó's book on *Aqueous Organometallic Catalysis* which followed three years after our own publication and which put the spotlight on Joó's special merits as one of the pioneers in aqueous biphasic catalysis. Up to now, most of the alternatives mentioned are only in a state of intensive development (except for one industrial realization: that of Swan/Chematur for hydrogenations in  $\text{scCO}_2$  [2]) but other pilot plant adaptations and even technical operations may be expected in the near future.

This second edition is based mainly on the state-of-the-art as described in the published literature up to the year 2003. To make things easier and to avoid errors, parts of the second edition are revised and updated, rather than rewritten. Thus, in some cases the order of the references is unchanged and new references are added without renumbering the existing ones (or substitute existing refs. by new items). The numbering of structures, equations, etc., was changed if necessary.

Once more we have to express our thanks not only to the authors and coauthors of the volume but also to the team at Wiley-VCH at Weinheim, especially Mrs. Claudia Grössl, for the production and their endless patience, and Dr. Elke Maase, the publishing editor. As with all our books, Mrs. Diana Boatman from Redhill, Surrey (UK), served as freelance copy-editor and was an invaluable help during the difficult process of completion. The Munich research group, especially PD Dr. F. E. Kühn, is acknowledged for scientific and technical assistance.

Hofheim and München  
January 2004

Boy Cornils  
Wolfgang A. Herrmann

## References

- [1] *Nachr. Chem.* **2003**, 51(5), 516.
- [2] B. Cornils, W. A. Herrmann, R. Schlögl, C.-H. Wong, *Catalysis from A to Z*, 2nd Edition, Wiley-VCH, Weinheim, **2003**, p. 746.



## Preface to the First Edition

This book describes homogeneously catalyzed reactions under two major boundary conditions: the catalysts employed are *organometallic* complexes that are used in the *aqueous phase*. In this respect the book is restricted to one area of homogeneous catalysis and therefore – though substantially expanded and more detailed – to one special area of our previous book, *Applied Homogeneous Catalysis with Organometallic Complexes* (VCH, Weinheim, Germany, 1996).

The subject of the book is the use of water-soluble organometallic catalysts for chemical reactions. These catalysts are so far the sole successful means of implementing the idea of *heterogenization* of homogeneous catalysts by *immobilizing* them with the aid of liquid supports. They thus solve the cardinal problem of homogeneous catalysis, which lies in the expensive separation of catalyst as well as product that is inherent in the system: the catalyst used in the homogeneous phase is separated by simply decanting the aqueous catalyst phase from the organic phase of the substrates and reaction products. Since all attempts to heterogenize homogeneous catalysts by immobilizing them on solid supports (“anchoring”) have to varying degrees been unsuccessful, only the use of homogeneous catalysts in aqueous solution and thus on liquid supports (“biphase operation”) leads to a neat, inexpensive solution to the problem that conserves resources and is therefore environmentally friendly.

This book is restricted essentially to *aqueous-phase* catalyses and thus to one area of the more comprehensively defined two-phase catalyses. This restriction to the most recent and successful development of homogeneous catalysis takes account of the rapid technical advances in the process concept first described by Manassen et al. in 1973, which was followed in rapid succession in the 1970s by hesitant basic work and in 1984 by the first commercial implementation. This unusual sequence – industrial implementation in a 100 000 tonnes per year oxo plant for the hydroformylation of propylene **before** years of time-consuming basic research to determine mechanistic, kinetic and other data – demonstrates clearly the great leap forward that this process development represented in the field of homogeneous catalysis and in solving the central problem mentioned earlier. Since then

other processes employing homogeneous catalysis have been converted to an aqueous two-phase procedure.

The development work intensified worldwide in various research groups in the years following the first commercial implementation at Ruhrchemie AG in Oberhausen. The obvious course of action was to let colleagues and specialists themselves report on their developments. This led to the formation of the international circle of contributors from the USA, France, the United Kingdom, China, Italy, Japan, India, Hungary and Germany which gives first-hand reports on its work.

One focus of the book is the hydroformylation process, the process involved in the first commercial implementation of aqueous-phase catalysis with its detailed descriptions of fundamental laws, special process features, and the present state of the art. Further focal points of the book are basic research on the complex catalysts (central atoms, ligands) and on the influence of the reaction conditions, solvents, and co-solvents, and a survey of other aqueous two-phase concepts and of proposed applications, with experimental examples and details. Environmental aspects are also considered.

We are sure that the outline chosen and the wide range of contributions from the authors give a multifaced and informative picture of the present state of developments in the field of aqueous two-phase catalysis, which presents not only the principles and accounts of the latest applications but also many aspects of spin-offs and alternative processes.

This description of ideas and process developments appears to us to be highly important for an appreciation of the potential of aqueous biphasic catalysis. The familiar assessment of the most important aspects of heterogeneous and homogeneous catalysis demonstrates that only in a solution of the problem of continuous separation of catalyst and product, such as becomes possible with the processes involving aqueous immobilized catalysts, in the key to further progress found. Only *homogeneous* catalysts that can be handled without problems will give us scientists and developers confidence that the clear and sure mechanistic understanding of their mode of action and the possibility of easy variability of steric and/or electronic properties can be transferred to other immobilized, and thus easy-to-handle, catalysts. More optimistically, it is hoped that this will apply especially to those heterogenized catalysts that basically are derived from tailor-made homogeneous catalysts.

The sharp line of demarcation between homogeneous and heterogeneous catalysis would thus be blurred and the possibility opened up of combining in one species the advantages of homogeneous catalysts and none of the disadvantages of heterogeneous catalysts: heterogenized homogeneous catalysts would lead to equally advantageous results as homogenized heterogeneous catalysts – the long-awaited dream of catalysis research would be fulfilled!

We thank the team at WILEY-VCH, especially Mrs. Diana Boatman, Dr. Anette Eckerle, and Mrs. Claudia Grössl for their cooperation during preparation of this book and for helpful technical assistance.

Dipl.-Chem. Kolja Wiczorek is acknowledged for preparing all formulas, figures, and schemes; Dipl.-Chem. Thomas Weskamp for the total index.

Frankfurt-Höchst and München  
Spring, 1998

Boy Cornils  
Wolfgang A. Herrmann



## Contents

<b>1</b>	<b>Introduction</b>	
1	Introduction ( <i>B. Cornils, W.A. Herrmann</i> )	3
<b>2</b>	<b>Basic Aqueous Chemistry</b>	
2.1	Organic Chemistry in Water ( <i>A. Lubineau, J. Augé, M.-C. Scherrmann</i> )	27
2.1.1	Introduction	27
2.1.2	Origin of the Reactivity in Water	28
2.1.3	Pericyclic Reactions	30
2.1.3.1	Diels–Alder Reactions	30
2.1.3.2	Hetero Diels–Alder Reactions	32
2.1.3.3	Other Cycloadditions	33
2.1.3.4	Claisen Rearrangements	33
2.1.4	Carbonyl Additions	34
2.1.4.1	Aldol-type Reactions	34
2.1.4.2	Michael-type Reactions	36
2.1.4.3	Allylation Reactions	36
2.1.5	Oxido-reductions	38
2.1.5.1	Oxidations	38
2.1.5.2	Reductions	38
2.1.6	Radical Reactions	39
2.1.7	Outlook	40
2.2	Organometallic Chemistry in Water ( <i>W.A. Herrmann, F.E. Kühn</i> )	44
2.2.1	Introduction	44
2.2.2	Water as a Solvent and Ligand	44
2.2.3	Organometallic Reactions of Water	46
2.2.4	Catalytic Reactions with Water	50
2.2.4.1	Water-gas Shift Reaction	50
2.2.4.2	Wacker–Hoechst Acetaldehyde Process	50

2.2.4.3	Olefin Hydration	51
2.2.4.4	Hydrodimerization	51
2.2.5	Water-soluble Metal Complexes	52
2.2.6	Perspectives	52
2.3	Characterization of Organometallic Compounds in Water ( <i>G. Laurenczy</i> )	57
2.3.1	Introduction	57
2.3.2	General Survey	57
2.3.3	Effect of High Hydrostatic Pressure on Aqueous Organometallic Systems	59
2.3.4	Aqueous Organometallics with Pressurized Gases	62
2.3.5	Concluding Remarks	65
<b>3</b>	<b>Catalysts for an Aqueous Catalysis</b>	
3.1	Variation of Central Atoms	71
3.1.1	Transition Metals ( <i>D.J. Darensbourg, C.G. Ortiz</i> )	71
3.1.1.1	Introduction	71
3.1.1.2	Water-soluble Catalysts by Virtue of Water-soluble Ligands	72
3.1.1.3	Water-soluble Catalysts through Water Coordination	82
3.1.2	Lanthanides in Aqueous-phase Catalysis ( <i>S. Kobayashi</i> )	88
3.1.2.1	Introduction	88
3.1.2.2	Aldol Reactions	89
3.1.2.3	Mannich-type Reactions	90
3.1.2.4	Diels–Alder Reactions	91
3.1.2.5	Micellar Systems	92
3.1.2.6	Asymmetric Catalysis in Aqueous Media	95
3.1.2.7	Conclusions	97
3.2	Variation of Ligands	100
3.2.1	Monophosphines ( <i>O. Stelzer†, S. Rossenbach, D. Hoff</i> )	100
3.2.1.1	General Features, Scope, and Limitations	100
3.2.1.2	Anionic Phosphines	101
3.2.1.3	Cationic Phosphines	112
3.2.1.4	Nonionic Water-soluble Phosphines	115
3.2.2	Diphosphines and Other Phosphines ( <i>M. Schreuder Goedheijt, P.C.J. Kamer, J.N.H. Reek, P.W.N.M. van Leeuwen</i> )	121
3.2.2.1	General	121
3.2.2.2	Diphosphines – Introduction of Sulfonate Groups by Direct Sulfonation	121
3.2.2.3	Introduction of Sulfonate Groups During Synthesis	123
3.2.2.4	Diphosphines with Quaternized Aminoalkyl or Aminoaryl Groups	125

- 3.2.2.5 Diphosphines with Hydroxyalkyl or Polyether Substituents 125
- 3.2.2.6 Carboxylated Diphosphines 128
- 3.2.2.7 Amphiphilic Diphosphines 129
- 3.2.2.8 Other Phosphines 130
- 3.2.3 Ligands or Complexes Containing Ancillary Functionalities  
(*P. Kalck, M. Urrutigoity*) 137
- 3.2.3.1 Complexes Containing at Least Two Classical Functionalities 137
- 3.2.3.2 Cationic Complexes 140
- 3.2.3.3 Immobilization on Silica Supports 143
- 3.2.3.4 Macromolecular Ligands or Supports 145
- 3.2.3.5 Ligands not Containing Phosphorus 151
- 3.2.3.6 Additional Perspectives 154
- 3.2.4 Tenside Ligands (*G. Papadogianakis*) 158
- 3.2.4.1 Introduction 158
- 3.2.4.2 Tenside Phosphines and Amines 159
- 3.2.4.3 Hydroformylation Reactions Catalyzed by Transition Metal Surfactant–  
Phosphine Complexes 161
- 3.2.4.4 Hydrogenation Reactions Catalyzed by Transition Metal Surfactant–  
Phosphine Complexes 168
- 3.2.4.5 Carbonylation Reactions Catalyzed by Transition Metal Surfactant–  
Phosphine Complexes 171
- 3.2.4.6 Concluding Remarks and Future Prospects 171
- 3.2.5 Chiral Ligands (*W.A. Herrmann, R.W. Eckl, F.E. Kühn*) 174
- 3.2.5.1 Introduction 174
- 3.2.5.2 Sulfonated Chiral Phosphines 174
- 3.2.5.3 Other Water-soluble Chiral Ligands 181
- 3.2.5.4 Conclusions 185
- 3.2.6 Other Concepts (*A. Börner*) 187
- 3.2.6.1 Hydroxyphosphines as Ligands 187
- 3.2.6.2 Amines and Polyoxometallates as Ligands  
(*W.A. Herrmann, C.-P. Reisinger*) 194

#### **4 Catalysis in Water as a Special Unit Operation**

- 4.1 Fundamentals of Biphasic Reactions in Water  
(*Y. Önal, M. Baerns, P. Claus*) 201
- 4.1.1 Introduction 201
- 4.1.2 Gas/Liquid-phase Reactions 203
- 4.1.3 Gas/Liquid/Liquid-phase Reactions 207
- 4.1.4 Place of Reaction in Aqueous Biphasic Systems 212
- 4.2 Technical Concepts (*A. Behr*) 219
- 4.2.1 Reaction Systems 219

4.2.2	Technical Realization: Variations	221
4.2.2.1	Reaction with Product Separation	223
4.2.2.2	Reaction and Product Extraction	224
4.2.2.3	Reaction and Product Treatment	227
4.2.2.4	Reaction and Catalyst Separation	227
4.2.2.5	Reaction and Catalyst Extraction	229
4.2.2.6	Reaction and Catalyst Treatment	231
4.2.3	Reaction Engineering Aspects	233
4.2.4	New Developments	234
4.2.4.1	Telomerization	234
4.2.4.2	Oligomerization	235
4.2.4.3	Hydrogenation	236
4.2.4.4	Hydroformylation	236
4.2.4.5	Other Reactions	237
4.3	Side Effects, Solvents, and Co-solvents ( <i>B. E. Hanson</i> )	243
4.3.1	Introduction	243
4.3.2	Hydroformylation	244
4.3.3	Hydrogenations and Other Catalytic Reactions	248
4.4	Membrane Techniques ( <i>H. Bahrman, B. Cornils</i> )	252
4.5	Micellar Systems ( <i>G. Oehme</i> )	256
4.5.1	Introduction	256
4.5.2	Hydrolytic Reactions in Micelles	259
4.5.3	Oxidation Reactions in Micelles	260
4.5.4	Complex-catalyzed Hydrogenation in Micellar Media	261
4.5.5	Carbon–Carbon Coupling Systems	264
4.5.6	Some Examples of Reactions in Reverse Micelles and Microemulsions	266
4.5.7	Perspectives	267
4.6	On the Borderline of Aqueous-phase Catalysis	272
4.6.1	Phase-transfer Catalysis ( <i>E. V. Dehmlow</i> )	272
4.6.1.1	General Overview, Fundamentals, and Definitions	272
4.6.1.2	Aqueous Organic-phase Heck and Other Cross Couplings under Phase-transfer Catalysis Conditions	275
4.6.1.3	Hydrogenations Mediated by Phase-transfer Catalysts	278
4.6.1.4	Biphasic Transfer Hydrogenations	280
4.6.1.5	Aqueous/Organic-phase Oxidations Mediated by Metal and PT Catalysts	280
4.6.1.6	Aqueous/Organic-phase Carbonylations	282
4.6.2	Counter-phase Transfer Catalysis ( <i>T. Okano</i> )	288
4.6.2.1	Introduction	288



- 4.6.2.2 Mechanism of the Counter-phase Transfer Catalytic Reaction 290
- 4.6.2.3 Counter-phase Transfer Catalytic Reactions 293
- 4.6.2.4 Concluding Remarks 297
- 4.6.3 Thermoregulated Phase-transfer and Thermoregulated Phase-separable Catalysis (*Z. Jin, Y. Wang, X. Zheng*) 301
  - 4.6.3.1 Introduction 301
  - 4.6.3.2 Thermoregulated Phase-transfer Catalysis with Nonionic Water-soluble Phosphines 302
  - 4.6.3.3 Hydroformylation of Higher Alkenes Based on TRPTC 305
  - 4.6.3.4 Thermoregulated Phase-separable Catalysis 307
  - 4.6.3.5 Conclusions 311
- 4.7 Transitions to Heterogeneous Techniques (SAPC and Variations) (*M.E. Davis*) 313
  - 4.7.1 Introduction 313
  - 4.7.2 The SAPC Concept of Immobilization 314
  - 4.7.3 Example of Rational Catalyst Design Strategy 318
  - 4.7.4 Suggested Reactions for Implementation of Design Concepts 321
  - 4.7.5 Outlook 322

## 5 Aqueous Catalysts for Environment and Safety

- 5.1 Water-soluble Organometallics in the Environment (*W.A. Herrmann, F.E. Kühn*) 327
  - 5.1.1 Introduction 327
  - 5.1.2 Biological Methylation 327
  - 5.1.3 Cobalamines – Organometallics in Nature 328
  - 5.1.4 Organoarsenic and Organotin Compounds 330
  - 5.1.5 Organomercury Compounds 331
  - 5.1.6 Other Metal-alkyl Complexes in the Environment 332
  - 5.1.7 Perspectives 334
- 5.2 Environmental and Safety Aspects (*B. Cornils, E. Wiebus*) 337
  - 5.2.1 Introduction 337
  - 5.2.2 The Ruhrchemie/Rhône-Poulenc (RCH/RP) Process 338
  - 5.2.3 Crucial Environmental Improvements 342
  - 5.2.4 Conclusions 345

## 6 Typical Reactions

- 6.1 Hydroformylation 351
  - 6.1.1 Development of the Commercial Biphase Oxo Synthesis (*B. Cornils, E.G. Kuntz*) 351
    - 6.1.1.1 History of Biphase Catalysis 351

- 6.1.1.2 Basic Work and Investigations by Rhône-Poulenc 353
- 6.1.1.3 Investigations by Ruhrchemie AG 355
- 6.1.1.4 The RCH/RP Process as the Final Point of Development 358
- 6.1.2 Kinetics (*R. V. Chaudhari, B. M. Bhanage*) 364
  - 6.1.2.1 Introduction 364
  - 6.1.2.2 Kinetics Using Water-soluble Catalysts 365
  - 6.1.2.3 Concluding Remarks 375
- 6.1.3 Reaction of Alkenes 377
  - 6.1.3.1 Lower Alkenes (*C. D. Frohning, C. W. Kohlpaintner*) 377
  - 6.1.3.2 Higher Alkenes (*H. Bahrmann, S. Bogdanovic, P. W. N. M. van Leeuwen*) 391
  - 6.1.3.3 Functionalized Alkenes (*E. Monflier, A. Mortreux*) 410
- 6.1.4 Re-immobilization Techniques (*H. Bahrmann*) 417
  - 6.1.4.1 Introduction 417
  - 6.1.4.2 Water-insoluble, Re-immobilized Liphophilic Ligands and Their Separation by Membrane Technique 418
  - 6.1.4.3 Separation and Use of Water-insoluble Ammonium Ligands in Hydroformylation 419
  - 6.1.4.4 Separation of Phosphine Oxides and Other Degradation Products 426
  - 6.1.4.5 Further Developments 426
- 6.2 Hydrogenation (*F. Joó, A. Kathó*) 429
  - 6.2.1 Introduction 429
  - 6.2.2 Mechanisms and Catalysts of Hydrogenations in Aqueous Solution 430
    - 6.2.2.1 Basic Mechanisms of Dihydrogen Activation 430
    - 6.2.2.2 Water-soluble Hydrogenation Catalysts with Tertiary Phosphine Ligands 431
    - 6.2.2.3 Complexes of Ligands with Donor Atoms Other Than Phosphorus(III) 440
  - 6.2.3 Typical Reactions 441
    - 6.2.3.1 Hydrogenation of Compounds with C=C and C≡C Bonds 441
    - 6.2.3.2 Hydrogenation of Compounds with C=O and C=N Bonds 451
    - 6.2.3.3 Hydrogenolysis of C–O, C–N, C–S, and C–Halogen Bonds 456
    - 6.2.3.4 Miscellaneous Hydrogenations 458
- 6.3 Hydrogenation and Hydrogenolysis of Thiophenic Molecules (*C. Bianchini, A. Meli*) 464
  - 6.3.1 Introduction 464
  - 6.3.2 Hydrogenation Reactions 465
  - 6.3.3 Hydrogenolysis Reactions 467
  - 6.3.4 Future Developments 471

6.4	Oxidations	473
6.4.1	Partial Oxidations ( <i>R.A. Sheldon, G. Papadogianakis</i> )	473
6.4.1.1	Introduction	473
6.4.1.2	Water-soluble Ligands	474
6.4.1.3	Concluding Remarks	479
6.4.2	Wacker-type Oxidations ( <i>E. Monflier, A. Mortreux</i> )	481
6.4.2.1	Possibilities of Wacker-type Oxidations	481
6.4.2.2	Conclusions	486
6.4.3	Methyltrioxorhenium(VII) as an Oxidation Catalyst ( <i>F.E. Kühn, W.A. Herrmann</i> )	488
6.4.3.1	Introduction	488
6.4.3.2	Synthesis of Methyltrioxorhenium(VII)	488
6.4.3.3	Behavior of Methyltrioxorhenium in Water	489
6.4.3.4	Catalyst Formation and Applications in Alkene Epoxidation	490
6.4.3.5	Other Oxidation Reactions	494
6.4.3.6	Perspectives	498
6.5	Carbonylation Reactions ( <i>M. Beller, J.G.E. Krauter</i> )	501
6.5.1	Introduction	501
6.5.2	Reductive Carbonylations	501
6.5.3	Carboxylation of C–X Derivatives	503
6.5.4	Hydrocarboxylation of Alkenes	508
6.5.5	Conclusions	508
6.6	C–C Coupling Reactions (Heck, Stille, Suzuki, etc.) ( <i>W.A. Herrmann, C.-P. Reisinger, P. Härter</i> )	511
6.6.1	Introduction	511
6.6.2	Catalysts and Reaction Conditions	512
6.6.3	Olefination	513
6.6.4	Alkyne Coupling	516
6.6.5	Cross-coupling Reactions	518
6.6.5.1	Suzuki Coupling	518
6.6.5.2	Stille Coupling	519
6.6.5.3	Miscellaneous	521
6.6.6	Conclusions	521
6.7	Hydrocyanation ( <i>H.E. Bryndza, J.A. Harrelson, Jr.</i> )	524
6.7.1	Introduction	524
6.7.2	HCN as a Synthon	524
6.7.2.1	Michael Additions of HCN to Activated Alkenes	524
6.7.2.2	Synthesis of Cyanohydrins from Ketones and Aldehydes	525
6.7.2.3	Strecker Synthesis of Aminonitriles	526
6.7.2.4	HCN Addition to Unactivated C=C Double Bonds	526

- 6.7.2.5 Cyanide Coupling Reactions 528
- 6.7.3 Summary 529
  
- 6.8 Allylic Substitution (*D. Sinou*) 532
  - 6.8.1 Introduction 532
  - 6.8.2 Scope of the Reaction 532
  - 6.8.3 Applications 535
  - 6.8.4 Conclusions 538
  
- 6.9 Hydrodimerization (*N. Yoshimura*) 540
  - 6.9.1 Introduction 540
  - 6.9.2 Development of Technologies 542
  - 6.9.3 Process of the Manufacture of 1-Octanol and Other Derivatives 545
  - 6.9.4 Applications 547
  
- 6.10 Alkene Metathesis (*R.H. Grubbs, D.M. Lynn*) 550
  - 6.10.1 Introduction 550
  - 6.10.2 "Classical" Group VIII Catalysts 551
  - 6.10.3 Polymers Prepared via Aqueous ROMP 554
  - 6.10.4 Alkylidenes as Catalysts 556
    - 6.10.4.1 Well-defined Ruthenium Alkylidenes 556
    - 6.10.4.2 Water-soluble Alkylidenes 557
  - 6.10.5 Summary 564
  
- 6.11 Asymmetric Synthesis (*D. Sinou*) 567
  
- 6.12 Catalytic Polymerization (*S. Mecking*) 576
  - 6.12.1 Introduction 576
  - 6.12.2 Copolymerization of Carbon Monoxide with Alkenes 577
  - 6.12.3 Polymerization of Ethylene and 1-Alkenes 578
  - 6.12.4 Polymerization of Conjugated Dienes 581
  - 6.12.5 Vinyl-type Polymerization of Cyclic Alkenes 582
  - 6.12.6 Ring Opening Metathesis Polymerization 583
  - 6.12.7 Polymerization of Alkynes 587
  - 6.12.8 Polymerization by Suzuki Coupling 587
  - 6.12.9 Summary and Outlook 589
  
- 6.13 Oleochemistry (*A. Behr*) 593
  - 6.13.1 Introduction 593
  - 6.13.2 Hydrogenation 593
  - 6.13.3 Hydroformylation 597
  - 6.13.4 Hydrocarboxylation 599
  - 6.13.5 Oxidation 600
  - 6.13.6 Oligomerization 602
  - 6.13.7 Hydrosilylation 602

- 6.13.8 Isomerization 603
- 6.14 Halogen Chemistry (*M. Bressan, A. Morvillo*) 606
  - 6.14.1 Introduction 606
  - 6.14.2 Reductive and Oxidative Dehalogenation 606
  - 6.14.3 Coupling and Carbonylation Reactions 609
- 6.15 Biological Conversions (*P.J. Quinn*) 613
  - 6.15.1 Introduction 613
  - 6.15.2 Biological Substrates 613
  - 6.15.3 Hydrogenation of Unsaturated Lipids in Aqueous Dispersions 614
    - 6.15.3.1 Water-insoluble Homogeneous Catalysts 616
    - 6.15.3.2 Water-soluble Homogeneous Catalysts 617
    - 6.15.3.3 Sources of Hydrogen 619
  - 6.15.4 Hydrogenation of Biological Membranes 620
    - 6.15.4.1 Topology of Unsaturated Lipids in Membranes 620
    - 6.15.4.2 Function of Unsaturated Lipids in Membranes 621
    - 6.15.4.3 Acclimation of Membranes to Low Temperature 622
    - 6.15.4.4 Membrane Unsaturation and Stability at High Temperatures 622
    - 6.15.4.5 Biochemical Homeostasis of Unsaturated Lipids 623
    - 6.15.4.6 Hydrogenation of Living Cells 624
  - 6.15.5 Conclusions 625
- 6.16 Other Recent Examples (*W.A. Herrmann, A.M. Santos, F.E. Kühn*) 627
  - 6.16.1 Introduction 627
  - 6.16.2 Isomerizations 627
  - 6.16.3 Aldolizations 628
  - 6.16.4 Hydroaminomethylation 630
  - 6.16.5 Aminations 631
  - 6.16.6 Hydrosilylations 631
  - 6.16.7 Thiolysis 632
  - 6.16.8 Synthesis of Various Heterocycles 633
- 7 Other Biphasic Concepts**
  - 7.1 Nonaqueous Organic/Organic Separation (SHOP Process) (*D. Vogt*) 639
    - 7.1.1 Introduction 639
    - 7.1.2 Process Description 640
  - 7.2 Catalysis in Fluorous Phases (*J.T. Horváth*) 646
    - 7.2.1 Introduction 646
    - 7.2.2 The Fluorous Concept 646
    - 7.2.3 Process and Applications 650

- 7.3 Nonaqueous Ionic Liquids (ILs, NAILs) (*H. Olivier-Bourbigou*) 655
  - 7.3.1 Introduction 655
  - 7.3.2 NAILs as a New Class of Solvents 655
  - 7.3.3 Applications in Organic Synthesis and Catalysis 657
    - 7.3.3.1 Salts Containing Strongly Coordinating Anions to Stabilize Anionic Complexes 657
    - 7.3.3.2 Salts Containing Weakly Coordinating Anions for Cationic and Molecular Complexes 658
    - 7.3.3.3 Salts Containing Chloroaluminate Anions as Solvents and Acidic Catalysts 660
    - 7.3.3.4 Supported Ionic Liquid Catalysis 661
    - 7.3.3.5 Solvents for Organic Reactions 661
  - 7.3.4 Concluding Remarks 662
- 7.4 Immobilization of Organometallic Catalysts Using Supercritical Fluids (*W. Leitner, A.M. Scurto*) 665
  - 7.4.1 Introduction 665
  - 7.4.2 Practical Approaches to Multiphase Catalysis Involving Supercritical Fluids 668
    - 7.4.2.1 Supercritical Fluids and Supported Catalysts 668
    - 7.4.2.2 Liquid/Supercritical Biphasic Systems 672
    - 7.4.2.3 Catalysis and Extraction Using sc Solutions (CESS) 678
  - 7.4.3 Conclusions and Outlook 682
- 7.5 The Amphiphilic Approach (*P.C.J. Kamer, J.N.H. Reek, P.W.N.M. van Leeuwen*) 686
  - 7.5.1 Separation Methods 686
    - 7.5.1.1 Two-phase Catalysis 686
    - 7.5.1.2 The Extraction Concept 688
  - 7.5.2 Use of Amphiphilic Phosphines 690
    - 7.5.2.1 Catalysis Using Amphiphilic Ligands 690
    - 7.5.2.2 Distribution Characteristics of the Free Ligands 693
    - 7.5.2.3 Rhodium Recycling 696
  - 7.5.3 Conclusions 697
- 7.6 Catalysis with Water-soluble Polymer-bound Ligands in Aqueous Solution (*S. Mecking, E. Schwab*) 699
  - 7.6.1 Introduction 699
  - 7.6.2 Catalysis with Water-soluble Polymer-bound Ligands in Aqueous Solution 700
  - 7.6.3 Conclusions 704

<b>8</b>	<b>Aqueous-phase Catalysis: The Way Ahead</b>	
8.1	State of the Art ( <i>B. Cornils, W.A. Herrmann</i> )	709
8.2	Improvements to Come	712
8.2.1	Reaction Engineering	713
8.2.2	Other Technologies	714
8.2.3	Other Feedstocks and Reactions	715
8.3	Focal Future Developments	717
	<b>Subject Index</b>	727

## Contributors

Prof. Dr. Jacques Augé  
Université de Cergy-Pontoise  
5, mail Gay-Lussac  
Neuville-sur-Oise  
F-95031 Cergy-Pontoise/France  
Tel: + 33/1 342 57051  
Fax: + 33/1 342 57067  
E-mail: jacques.auge@chim.u-cergy.fr

Prof. Dr. Manfred Baerns  
Institut für Angewandte Chemie  
Berlin-Adlershof e. V.  
Rudower Chaussee 5  
D-12484 Berlin/Germany  
Tel: + 49/30 6392 4444  
Fax: + 49/30 6392 4454  
E-mail: mbaerns@aol.com

Dr. Helmut Bahrmann  
Celanese GmbH/Werk Ruhrchemie  
Postfach 13 01 60  
D-46128 Oberhausen/Germany  
Tel: + 49/208 693 2201  
Fax: + 49/208 693 2291

Prof. Dr. Arno Behr  
Universität Dortmund  
Fachbereich Chemietechnik  
Lehrstuhl für Technische Chemie A  
Emil-Figge-Str. 66  
D-44227 Dortmund/Germany  
Tel: + 49/231 755 2310  
Fax: + 49/231 755 2311  
E-mail: arno.behr@bci.uni-dortmund.de

Prof. Dr. Matthias Beller  
Leibnitz-Institut für Organische Katalyse  
an der Universität Rostock  
Buchbinderstr. 5–6  
D-18055 Rostock/Germany  
Tel: + 49/381 466 9313  
Fax: + 49/381 466 9324  
E-mail: Matthias.Beller@ifok.uni-  
rostock.de

Dr. Bhalchandra M. Bhanage  
Division of Materials Science and  
Engineering  
Hokkaido University  
Kita 13 Nishi 8, Kita-ku  
Sapporo 060-8628/Japan  
Tel: + 81/11706 6597  
Fax: + 81/11706 6594  
E-Mail: bhanage@proc-ms.eng.  
hokudai.ac.jp



Dr. Claudio Bianchini  
Istituto per lo Studio della Stereochimica  
ed Energetica dei Composti  
CNR di Coordinazione  
Via J. Nardi, 39  
I-50132 Firenze/Italy  
Tel: + 39/55 243 990/24 5990  
Fax: + 39/55 247 8366  
E-mail: bianchini@fi.cnr.it

Dr. Sandra Bogdanovic  
Booz Allen Hamilton  
Lenbachplatz 3  
D-80333 München/Germany  
Tel.: + 49/89 545 250  
Fax.: + 49/89 545 25 500

Prof. Dr. Armin Börner  
Universität Rostock  
Fachbereich Chemie  
Albert-Einstein-Str. 3a  
D-18059 Rostock/Germany  
Tel.: + 49/381 466 6931/350  
Fax: + 49/381 466 9324  
E-mail: armin.boerner@ifok.uni-  
rostock.de

Prof. Dr. Mario Bressan  
Università G. D'Annunzio  
Dipartimento di Scienze  
Viale Pindaro 42  
I-65127 Pescara/Italy  
Tel: + 39/85 453 7548  
Fax: + 39/85 453 7545  
E-mail: bressan@sci.unich.it

Dr. Henry R. Bryndza  
DuPont Nylon  
Experimental Station, Bldg. 302  
P.O. Box 80328  
Wilmington, Delaware 19880-0302/USA  
Tel: + 1/302 695 3761  
Fax: + 1/302 695 9084  
E-mail: Bryndza@esvax.enet.duPont.com

Prof. Dr. Raghunath V. Chaudhari  
National Chemical Laboratory  
Pune 411 008/India  
Tel: + 91/2025 893 163  
Fax: + 91/2025 893 260  
E-mail: rvc@ems.ncl.res.in

Prof. Dr. Peter Claus  
Technische Universität Darmstadt  
Institut für Technische Chemie und  
Makromolekulare Chemie  
Petersenstr. 20  
D-64287 Darmstadt/Germany  
Tel: + 49/6151 16 5369  
Fax: + 49/6151 16 4788  
E-mail: claus@ct.chemie.tu-  
darmstadt.de

Prof. Dr. Boy Cornils  
Kirschgartenstr. 6  
D-65719 Hofheim/Germany  
Tel: + 49/6192 23502  
Fax: + 49/6192 23502  
E-mail: boy.cornils@t-online.de

Prof. Donald Darensbourg  
Texas A&M University  
Department of Chemistry  
PO Box 30012  
College Station, Texas 77892-3012/USA  
Tel: + 1/979 845 5417  
Fax: + 1/979 845 0158  
E-mail: djdarens@mail.chem.tamu.edu

Prof. Dr. Mark E. Davis  
Chemical Engineering  
California Institute of Technology  
Pasadena, California 91125/USA  
Tel: + 1/626 395 4251  
Fax: + 1/626 568 8143  
E-mail: mdavis@cheme.caltech.edu

Prof. Dr. Eckehard V. Dehmlow  
Universität Bielefeld  
Fakultät für Chemie  
Universitätsstr. 25  
D-33615 Bielefeld/Germany  
Tel: + 49/521 106 2051  
Fax: + 49/521 106 6146  
E-mail: Dehmlow@post.uni-bielefeld.de

Dipl.-Chem. Robert W. Eckl  
morphochem AG  
Gmundener Str. 37–37a  
D-81379 München/Germany  
E-mail: robert.eckl@morphochem.de

Dr. Carl D. Frohning  
Celanese GmbH/Werk Ruhrchemie  
Postfach 13 01 60  
D-46128 Oberhausen/Germany  
Tel: + 49/208 693 2419  
Fax: + 49/208 693 2291  
E-mail: Frohning@cityweb.de

Prof. Dr. Robert H. Grubbs  
Division of Chemistry  
and Chemical Engineering  
California Institute of Technology  
Pasadena, California 91125/USA  
Tel: + 1/626 395 6003  
Fax: + 1/626 564 9297  
E-mail: rhg@its.caltech.edu

Prof. Dr. Brian E. Hanson  
Virginia Polytechnic Institute  
and State University  
Department of Chemistry  
College of Arts and Sciences  
Blacksburg, Virginia 24061-0212/USA  
Tel: + 1/540 231 7206  
Fax: + 1/540 231 3255  
E-mail: hanson@vt.edu

Dr. John A. Harrelson, Jr.  
DuPont Nylon  
Experimental Station, Bldg. 302  
P.O. Box 80328  
Wilmington, Delaware 19880-0302/USA  
Tel: + 1/302 695 3761  
Fax: + 1/302 695 9084

PD Dr. Peter Härter  
Technische Universität München  
Anorganisch-chemisches Institut  
Lichtenbergstr. 4  
D-85747 Garching/Germany  
Tel: + 49/89 2891 3099  
Fax: + 49/89 2891 3473  
E-mail: peter.haerter@ch.tum.de

Prof. Dr. Wolfgang A. Herrmann  
President of the  
Technische Universität München  
Arcisstr. 21  
D-80333 München/Germany  
Tel: + 49/89 2892 2200  
Fax: + 49/89 2892 3399  
E-mail: sekretariat.ac@ch.tum.de

Dr. Dietmar Hoff  
Rheinchemie  
Paul-Ehrlich-Str. 10  
D-67122 Altrip/Germany  
E-mail: dietmar.hoff@rheinchemie.com

Prof. Dr. István T. Horváth  
Eötvös University  
Department of Chemical Technology  
and Environmental Chemistry  
Pázmány Péter sétány 1/A  
H-1117 Budapest/Hungary  
Tel: + 31/1 2090590  
Fax: + 31/1 2090607  
E-mail: istvan.t.horvath@hit-team.net

Prof. Dr. Zilin Jin  
State Key Laboratory of Fine Chemicals  
Dalian University of Technology  
116012 Dalian/China  
Tel: + 86/411 467 1511  
Fax: + 86/411 363 3080  
E-mail: hpcuo@mail.dlptt.ln.cn

Prof. Dr. Ferenc Joó  
University of Debrecen and  
Hungarian Academy of Sciences  
P.O. Box 7  
H-4010 Debrecen/Hungary  
Tel: + 36/52 512 900  
Fax: + 36/52 512 915  
E-mail: jooferenc@tigris.klte.hu

Prof. Dr. Philippe Kalck  
Ecole Nationale Supérieure  
des Ingénieurs en Arts Chimiques  
et Technologique (ENSIACET)  
118, Route de Narbonne  
F-31077 Toulouse Cedex 04/France  
Tel: + 33/562 885 690  
Fax: + 33/562 885 600  
E-mail: Philippe.Kalck@ensiacet.fr

Dr. Paul C. J. Kamer  
University of Amsterdam  
Institute for Molecular Chemistry  
Inorganic Chemistry & Homogeneous  
Catalysis  
Nieuwe Achtergracht 166  
NL-1018 WV Amsterdam  
The Netherlands  
Tel: + 31/20 525 6495/6454  
Fax: + 31/20 525 6456

Dr. Agnes Kathó  
University of Debrecen and  
Hungarian Academy of Sciences  
P.O. Box 7  
H-4010 Debrecen/Hungary  
Tel: + 36/52 512 900  
Fax: + 36/52 512 915  
E-mail: katho@tigris.klte.hu

Prof. Dr. Shu Kobayashi  
Graduate School of Pharmaceutical  
Sciences  
The University of Tokyo  
Hongo, Bunkyo-ku  
Tokyo 113-0033/Japan  
E-Mail: skobayas@mol.fu-tokyo.ac.jp

Dr. Christian W. Kohlpaintner  
Chemische Fabrik Budenheim  
Rheinstr. 27  
D-55257 Budenheim/Germany  
Tel: + 49/6139 89495  
Fax: + 49/6139 89464  
E-mail: ckohlpaintner@budenheim-  
cfb.com

Dr. Jürgen G.E. Krauter  
Degussa AG  
Rodenbacher Chaussee 4  
D-63457 Hanau-Wolfgang/Germany  
E-mail: juergen.krauter@degussa.com

PD Dr. Fritz E. Kühn  
Technische Universität München  
Anorganisch-chemisches Institut  
Lichtenbergstr. 4  
D-85747 Garching/Germany  
Tel: + 49/89 2891 3105  
Fax: + 49/89 2891 3473  
E-mail: fritz.kuehn@chem.tum.de

Dr. Emile G. Kuntz  
CPE-LYON – Laboratoire  
d'Electrochimie Analytique  
43, Bd du 11 Novembre 1918  
F-69616 Villeurbanne/France  
Tel: + 33/472 448 478  
Fax: + 33/472 448 479

Prof. Dr. Gábor Laurenczy  
Institut de Chimie Minerale et  
Analytique  
Batiment de Chimie (BCH)  
CH-1015 Dorigny Lausanne/Suisse  
Tel: + 41/21693 9858  
Fax: + 41/21693 9865  
E-mail: gabor.laurenczy@epfl.ch

Prof. Dr. Piet W. N. M. van Leeuwen  
University of Amsterdam  
Institute for Molecular Chemistry  
Inorganic Chemistry & Homogeneous  
Catalysis  
Nieuwe Achtergracht 166  
NL-1018 WV Amsterdam  
The Netherlands  
Tel: + 31/20 525 5419  
Fax: + 31/20 525 6422  
E-mail: pwnm@anorg.chem.uva.nl

Prof. Dr. Walter Leitner  
Lehrstuhl für Technische Chemie  
und Petrolchemie  
RWTH-Aachen  
Worringer Weg 1  
D-52056 Aachen/Germany  
Tel: + 49/241 802 6480  
Fax: + 49/241 802 2177  
E-mail: leitner@itmc.rwth-aachen.de

Prof. Dr. André Lubineau  
Laboratoire de Chimie Organique  
Multifonctionnelle  
Université de Paris-Sud  
Bat. 420  
F-91405 Orsay/France  
Tel: + 33/169 157 233  
Fax: + 33/169 154 715  
E-mail: lubin@icmo.u-psud.fr

Dr. David M. Lynn  
Laboratories of Chemistry  
California Institute of Technology  
Pasadena, California 91125/USA  
Tel: + 1/626 395 6003  
Fax: + 1/626 564 9297

PD Dr. Stefan Mecking  
Albert-Ludwigs-Universität  
Institut für Makromolekulare Chemie  
Stefan-Meier-Str. 31  
D-79104 Freiburg/Germany  
Tel: + 49/761 203 6304  
Fax: + 49/761 203 6319  
E-mail: stefan.mecking@makro.uni-  
freiburg.de

Dr. Andrea Meli  
Istituto per lo Studio della Stereochemica  
ed Energetica dei Composti  
CNR di Coordinazione  
Via J. Nardi, 39  
I-50132 Firenze/Italy  
Tel: + 39/55 243 990 245 990  
Fax: + 39/55 247 8366

Prof. Dr. Eric Monflier  
Université d'Artois  
Faculté des Sciences J. Perrin/  
Laboratoire de Physicochimie des  
Interfaces – CRUAL  
Rue Jean Souvraz – Sac postal 18  
F-62307 Lens/France  
Tel: + 33/321 791 715  
Fax: + 33/321 791 717  
E-mail: monflier@univ-artois.fr

Prof. Dr. André Mortreux  
Université des Sciences et Technologies  
de Lille  
Ecole Nationale Supérieure de Chimie  
de Lille  
B.P. 108  
F-59652 Villeneuve d'Ascq Cédex/France  
Tel: + 33/320 434 993  
Fax: + 33/320 436 585  
E-Mail: andre.mortreux@enac-lille.fr

Prof. Dr. Antonino Morvillo  
Università di Padova  
Dipartimento di Chimica Inorganica  
Via Marzolo 1  
I-35100 Padova/Italy  
Tel: + 39/49 827 5156  
Fax: + 39/49 827 5161

Prof. Dr. Günther Oehme  
Institut für Organische Katalyseforschung  
an der Universität Rostock e. V.  
Buchbinderstr. 5–6  
D-18055 Rostock/Germany  
Tel: + 49/381 466 930  
Fax: + 49/381 466 9324  
E-mail: guenther.oehme@ifok.uni-  
rostock.de

Prof. Dr. Tamon Okano  
Department of Materials Science  
Faculty of Engineering  
Tottori University  
Tottori 680/Japan  
Tel: + 81/857 31 5260  
Fax: + 81/857 31 0881  
E-Mail: okano@che.tottori-u.ac.jp

Prof. Dr. Hélène Olivier-Bourbigou  
Institut Français du Pétrole  
1–4 Avenue de bois Préau  
F-92852 Rueil-Malmaison Cédex  
France  
Tel: + 33/1 475 26779  
Fax: + 33/1 475 26055  
E-mail: helene.olivier-bourbigou@ifp.fr

Dr. Yücel Önal  
Technische Universität Darmstadt  
Institut für Technische Chemie und  
Makromolekulare Chemie  
Petersenstr. 20  
D-64287 Darmstadt/Germany  
Tel: +49/6151 16 3766  
Fax: +49/6151 16 4788  
E-mail: oenal@ct.chemie.tu-  
darmstadt.de

Dr. Cesar G. Ortiz  
Texas A&M University  
Department of Chemistry  
PO Box 30012  
College Station, Texas 77892-3012  
USA  
Tel: +1/979 845 5417  
Fax: +1/979 845 0158

Prof. Dr. Georgios Papadogianakis  
University of Athens  
Department of Chemistry  
Industrial Chemistry Laboratory  
Panepistimiopolis – Zografou  
GR-15771 Athens/Greece  
Tel: +30/17284235  
Fax: +30/17249103  
E-mail: papadogianakis@chem.uoa.gr

Prof. Dr. Peter J. Quinn  
King's College London  
Section of Biochemistry  
Campden Hill  
GB-London W8 7AH/Great Britain  
Tel: +44/171 333 4408  
Fax: +44/171 333 4500  
E-mail: p.quinn@kcl.ac.uk

Dr. J.N.H. Reek  
University of Amsterdam  
Institute of Molecular Chemistry  
Homogeneous Catalysis  
Nieuwe Achtergracht 166  
NL-1018 WV Amsterdam  
The Netherlands  
Tel: +31/20 525 6437  
Fax: +31/20 525 6422  
E-mail: reek@science.uva.nl

Dr. Claus-Peter Reisinger  
Business Development  
Exatec LLC  
31220 Oak Creek Drive  
Wixom, Michigan 48393/USA  
E-Mail: www.exatec.biz

Dr. Stefan Rossenbach  
Bergische Universität  
Gauss-Str. 20  
D-42047 Wuppertal

Dr. Ana M. Santos  
Technische Universität München  
Anorganisch-chemisches Institut  
Lichtenbergstr. 4  
D-85747 Garching/Germany  
Tel: +49/89 2891 3102  
Fax: +49/89 2891 3473  
E-mail: ana.kuehn@ch.tum.de

Dr. Marie-Christine Scherrmann  
Laboratoire de Chimie Organique  
Multifonctionnelle  
Université de Paris-Sud, Bat 420  
F-91405 Orsay/France  
Tel: +33/1691 54719  
Fax: +33/1691 54715  
E-mail: mcscherr@icmo.u-psud.fr