

Chemistry of Coal Utilization

SECOND SUPPLEMENTARY VOLUME

**Prepared Under the Guidance of
the Committee on Chemistry of Coal Utilization**

Edited by

MARTIN A. ELLIOTT

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This volume has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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SECOND SUPPLEMENTARY VOLUME

To Homer H. Lowry, an outstanding coal scientist, who brought into being the first three volumes of this work so extensively used and greatly appreciated by workers in coal science and coal technology

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Preface

The first two volumes of this work, published in 1945, and the first supplemental volume, published in 1963, all under the editorship of H. H. Lowry, are recognized classics. Their comprehensive coverage and critical review of the literature on coal science and technology have been invaluable to workers at all levels of experience. Between 1963 and 1976, however, funding of coal research and development by government and industry in the United States increased from about \$22 million to about \$322 million per year. Throughout this period the expansion in the literature on coal science and technology and in the number of newcomers to the field made evident the need for a second supplementary volume to *Chemistry of Coal Utilization*.

Seymour Alpert, Electric Power Research Institute, and George R. Hill, University of Utah (formerly of Electric Power Research Institute), began to lay the groundwork for a second supplement as early as 1974. The new volume was not to replace the earlier volumes but was to bring up to date the review of the state of knowledge of the science and technology of coal utilization. The publisher agreed to reprint the first two volumes and to keep the first supplemental volume in print during the lifetime of the new supplement.

The earlier volumes had been prepared and published under the auspices of the National Research Council (NRC) of the National Academy of Sciences, and the Council was approached again about its interest in overseeing the current review. The NRC accepted the task and assigned it to the Board on Energy Studies under the NRC's Commission on Natural Resources. In September 1975 the board selected George R. Hill as chairman of a project steering committee, and I agreed to serve as Technical Editor. (Dr. Lowry died in 1971.) A contract providing financial support was signed between the U.S. Energy Research and Development Administration (ERDA) and the NRC in February 1976, and work under the contract began at once. In mid-February the following appointments to the Steering Committee were announced: George R. Hill (Chairman), University of Utah; Norbert Berkowitz, University of Alberta; Joan L. Coles, Utah Energy Conservation and Development Council; R. Tracy Eddinger, Cogas Development Company; Lionel S. Galstaun, Bechtel Incorporated; James R. Garvey, Bituminous Coal Research, Inc.; John M. Holmes, Oak Ridge National Laboratory; Hoyt C. Hottel, Massachusetts Institute of Technology; Henry R. Linden, Gas Research Institute; Johnstone S. Mackay, U.S. Steel Corporation; Douglas S. Montgomery, University of Alberta; Harry Perry, Resources for the Future; Eric H. Reichl, CONOCO Coal Development Company; Jack A. Simon, Illinois State Geological Survey; and Lawrence E. Swabb, Jr., Exxon Research and Engineering Company.

At its first meeting the Steering Committee approved the division of the task into chapters and suggested the names of authorities to write them. Sixty internationally recognized experts accepted the committee's invitation to write or collaborate on individual chapters, and the committee added four chapters dealing with topics not found in the earlier volumes: Chapter 1, The Coal Industry and Coal Research and Development in Perspective; Chapter 2, Coal Resources; Chapter 22, Control of Pollution from Combustion Processes; and Chapter 31, Environmental, Health and Safety Implications of Increased Coal Utilization. In addition, the broad areas of pyrolysis, combustion, gasification, and liquefaction were subdivided for treatment in three separate chapters on fundamentals, processes, and treatment of products. One committee member was assigned responsibility for the technical review of each of the 31 chapters. (The Acknowledgments that follow this Preface specify the designated members and their assignments.)

All the authors had been selected and all but one of the chapter outlines had been submitted before the second meeting of the Steering Committee in May 1976. At that time it was decided that I would suggest reviewers for the individual chapters, in consultation and agreement with the other committee members. (The Acknowledgments section lists the names of those who reviewed manuscripts and who contributed so substantially to the quality of the final product.)

The first manuscript was received in August 1976, the last in December 1978. Because of this unavoidable time spread, the cutoff date of the coverage of the literature varies from chapter to chapter just as it did in the first supplement. The current authors were asked to pick up review of their topics at the point where the antecedent chapter in the earlier volume left off and to bring the review down to the time of completion of their individual manuscripts. The completed manuscript was sent to the publisher in the spring of 1979.

The basic philosophy of the second supplemental volume is the same as that stated by Dr. Lowry in his preface to the first supplement. He wrote that the manuscripts were to

include critical reviews of important world literature [through 1958]. Complete bibliographic coverage was to be considered less important than reference to the more significant publications. Both sides of controversial subjects were to be documented. Each chapter was to be reviewed by competent people in the field of activity covered, the reviewers being selected by consultation with members of the Committee on Chemistry of Coal Utilization. The review system was to be designed to avoid undue emphasis on particular subjects solely because of immediate personal interests of the authors . . .

Authors of the current volume are solely responsible for the technical content and conclusions in their chapters. Certain minor changes in the text were made in the editorial process for the sake of uniformity. I take full responsibility for the following policy decisions.

Units The form to be followed in using units in the individual chapters was left to the discretion of the authors. In the chapters dealing with coal science, c.g.s. units were used consistently. In certain chapters dealing with coal technology, the form used by the authors of the referenced articles was followed. Thus both c.g.s. and f.p.s. units may appear in the same chapter.

maf and daf Throughout the book, "maf" is used consistently for "moisture-and-ash-free" basis. This decision was made before I learned that some of the authors had a strong preference for the use of "daf" for the "dry-ash-free" basis, which in certain instances is less ambiguous than maf. The point is brought out here to prevent confusion, since some articles in the literature by authors of chapters in this book advocate use of "daf," yet the term "maf" appears in chapters they wrote for this book.

Repetition of subject matter I believe that some repetition of material from chapter to chapter is justified if it allows the discussion in each chapter to be more self-contained and minimizes or avoids interruptions by cross-references. As it turns out, there is comparatively little repetition among chapters, and where it does occur, it contributes to continuity of presentation.

Economics The Steering Committee decided that data on economics should not be incorporated into the technical discussions. The decision was made because of rapidly changing economic conditions as a result of inflation, and because differences in assumptions make economic estimates from different sources generally not comparable. In a few instances economic estimates were made by the same organization and used, not in the absolute sense, but for comparative purposes between technologies. In those few instances, I included economic comparisons to allow for more comprehensive coverage of the subject.

Glossary The bewildering array of acronyms that has come into use in the past decade, for government entities and other organizations as well as for processes and procedures, made a glossary indispensable.

One of the primary objectives of everyone participating in this effort was to make the finished product as widely available as possible. To that end we have made every effort commensurate with maintaining quality to hold down the list price of the published book. The NRC provided partial restitution of income foregone and out-of-pocket expenses incurred for

only 11 of the many contributors. In the case of the earlier volumes, no royalties were paid by the publisher either to the NRC or to any of the authors. Recent National Academy of Sciences policy provides for royalties to be paid to the NRC on privately published sales of reports for which there may be high demand. In accord with that policy the contractual agreement concerning this volume provides for royalties to be paid to the NRC if the total number of copies sold exceeds 5000. Any money received under these terms will be placed in a special trust fund to support the preparation of the next volume in the *Chemistry of Coal Utilization* series.

The efforts of everyone involved in this ambitious undertaking will be more than amply rewarded if, as we hope, the wealth of scientific and technical knowledge contained here assists the nation in utilizing efficiently its vast coal resource.

MARTIN A. ELLIOTT

Technical Editor
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Houston, Texas
January 1981

Acknowledgments

Obvious though it is, it must be stressed again that this book is the aggregate of the contributions of its authors. Their knowledge and experience and their skill at distilling what they had learned into the chapters that follow have, alone, made the present volume possible. Words cannot express my gratitude for the dedication of the authors to their task, or the pride I have taken in the privilege of serving as technical editor.

For an effort of this magnitude many individuals in addition to the authors made contributions, and it is a pleasure to acknowledge them.

Ernest E. Donath did a superb job of translating into English the four chapters written in German. The difficulties presented to the translator by the subtle distinctions in terminology cannot be overestimated. Dr. Donath surmounted them all.

The work of the Steering Committee and its chairman in advising and guiding me and in reviewing manuscripts was of inestimable value. The contribution of the committee members responsible for carrying out their special roles also deserves our particular notice. The committee members bore responsibility for chapters as follows: N. Berkowitz, Chapters 4, 5, 7, 8; J. Coles, Chapter 31; T. Eddinger, Chapters 12, 13, 14; L. Galstaun, Chapters 23, 24, 25; J. Garvey, Chapters 9, 10, 11, 20; J. Holmes, Chapters 6, 21; H. Hottel, Chapter 19; H. Linden, Chapter 1; J. Mackay, Chapters 26, 30; D. Montgomery, Chapters 15, 16, 17, 18; H. Perry, Chapter 22; J. Simon, Chapters 2, 3; L. Swabb, Chapters 27, 28, 29.

The reviewers listed below contributed generously and willingly of their time and abilities and played a crucial role in our efforts to maintain the high standards set by the earlier volumes. In alphabetical order they were Clayton G. Ball, Paul Weir Company, Inc.; Harold Beuther, Gulf Oil Research and Development; Charles Brandenburg, U.S. Energy Research and Development Administration; Irving Breger, U.S. Geological Survey; John Burchard, U.S. Environmental Protection Agency; Thomas G. Callcott, Broken Hill Proprietary Company, Ltd.; John Campbell, University of California; Richard Carpenter, East-West Environment and Policy Institute; Ralph L. Coates, Brigham Young University; Henry O. Cochran, Jr., Oak Ridge National Laboratory; Anthony Colucci, Electric Power Research Institute; Cyril Comar, Electric Power Research Institute; Arthur L. Conn, Amoco Research and Development Center; Richard Corey, U.S. Energy Research and Development Administration; William L. Crentz, U.S. Energy Research and Development Administration; Ernest Donath, Consultant; Sabri Ergun, Consultant; Harold Falkenberry, Tennessee Valley Authority; B. T. Fant, Exxon Research and Engineering Company; A. J. Forney, Consultant; L. D. Freidman, Cogas Development Company; J. F. Fryer, Alberta Research Council; Peter Given, Pennsylvania State University; Ralph Gray, U.S. Steel Corporation; Robert A. Graff, City University of New York; George Haddad, U.S. Steel Corporation; William J. Halvorsen, Consolidation Coal Company; Homer E. Harris, Eastern Associated Coal Corporation; Roy Helfenstine, Illinois Geological Survey; J. F. Hiorns, Consultant; Gerald A. Hollinden, Tennessee Valley Authority; Michael Holowaty, Inland Steel Corporation; Jack Howard, Massachusetts Institute of Technology; H. Raymond Hoy, British Coal Utilisation Research Association; Arthur Ingberman, Union Carbide Corporation; Clarence Karr, U.S. Energy Research and Development Administration; Raphael Kasper, National Research Council; Arthur Kohl, Rockwell International; George Land, Amax Coal Company; Bert Louks, Stanford Research Institute; Michael McCloskey, Sierra Club; Wayne A. McCurdy, U.S. Energy Research and Development Administration; D. G. Madley, Coal Research Establishment; Michael Massey, Carnegie-

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Many members of the NRC staff contributed in a variety of ways to the project. Winfred E. Berg, Special Projects Officer of the Commission on Natural Resources, initiated and assisted in establishing the project through negotiations with ERDA and, subsequently, the U.S. Department of Energy (DOE). Captain Berg also helped to set up the Steering Committee, and throughout the project we had the benefit of his unflagging interest and wise counsel.

I am deeply indebted to George White, Executive Secretary of the Committee on Chemistry of Coal Utilization. His administrative ability, dedication, competence, and diligence were major factors in ensuring the success of this project. Also indispensable was Erika Douglas, without whose competence, dedication, thoroughness, and diligence it would not have been possible to put the manuscript into final form for publication.

It is a particular pleasure to acknowledge the performances of these outstanding staff officers: Robert C. Rooney, Philippa Shepherd, Maggie Elliott, Claire Chow, Judith Cummings, and Anne Norman, editors at the Commission on Natural Resources, who assisted with the innumerable editorial tasks involved in readying the manuscript for the printer. The exhaustive subject index is the work of Bev Anne Ross. Estelle Miller, Barbara Brown, Ralph Davis, and David Savage, of the Manuscript Processing Unit, brought the computer to bear on our manuscript preparation needs for first draft to final copy. The Academy's Office of Publications consulted on details of production and contractual publishing arrangements.

Finally, to acknowledge the support without which the entire project could not have been undertaken or completed, I express my appreciation to ERDA/DOE and to their representatives responsible for contractual arrangements with the NRC, Ray Zahradnik, Martin Neuworth, and James Batchelor.

Dr. G. Robert Yohe, co-author of Chapter 1, "The Coal Industry and Coal Research and Development in Perspective," died in August 1979. Dr. Yohe had a long and distinguished career in the field of coal chemistry. Those associated with the preparation of this volume and his colleagues were saddened to see his productive career ended.

The Steering Committee, the Technical Editor, and the NRC staff were also saddened by the premature death of Dr. James L. Johnson, author of Chapter 23, "Fundamentals of Coal Gasification." Dr. Johnson's many outstanding contributions to science and technology had already received international recognition within his lifetime. It was our pleasure to cooperate with the Institute of Gas Technology in a memorial volume containing a collection of Dr. Johnson's writings by making available for inclusion the chapter written by him for the *Second Supplementary Volume to Chemistry of Coal Utilization*.

M.A.E.

Chemistry of Coal Utilization

SECOND SUPPLEMENTARY VOLUME

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