

Contents

| | |
|----------------------------|------|
| Preface | xiii |
| List of Contributors | xv |
| Introduction | xvii |

| | |
|--|------|
| <i>Linda E. Sugiyama</i> | |
| Part I: Global and Large-Scale Environmental Processes and Modifications | xvii |
| Part II: Energy Use and Conservation | xxi |
| Part III: Waste Treatment: Prevention and Remediation | xxii |
| Acknowledgments | xxv |
| References | xxv |

Part I . Global and Large-Scale Environmental Processes and Modifications

| | |
|---|----|
| Chapter 1 A Brief Introduction to Global Change | 3 |
| <i>Herbert Gursky</i> | |
| 1.1 Introduction | 3 |
| 1.2 Scientific Complexity | 4 |
| 1.3 Global Warming | 5 |
| 1.4 Ozone Depletion | 9 |
| 1.5 The Institutional Response | 12 |
| 1.6 Summary | 12 |
| References | 13 |

| | |
|--|----|
| Chapter 2 Global Change and Possible Effects on the Earth's Plasma Environment | 15 |
| <i>Raymond G. Roble</i> | |
| 2.1 Introduction | 15 |
| 2.2 Changes in Global Mean Atmosphere Structure | 16 |
| 2.3 Changes in Ionospheric Structure | 25 |
| 2.4 Global Electric Circuit | 31 |

Cover: Photograph courtesy of Melvin L. Prueitt, Los Alamos National Laboratory.

In recognition of the importance of preserving what has been written, it is a policy of the American Institute of Physics to have books published in the United States printed on acid-free paper.

©1997 by American Institute of Physics

All rights reserved.

Printed in the United States of America.

Reproduction or translation of any part of this work beyond that permitted by Section 107 or 108 of the 1976 United States Copyright act without the permission of the copyright owner is unlawful. Requests for permission or further information should be addressed to the Office of Rights and Permissions, 500 Sunnyside Boulevard, Woodbury, NY 11797-2999; phone: 516-576-2268; fax: 516-576-2499; e-mail: rights@aip.org.

AIP Press
American Institute of Physics
500 Sunnyside Boulevard
Woodbury, NY 11797-2999

Library of Congress Cataloging-in-Publication Data
Plasma science and the environment / edited by Wallace Manheimer,
Linda E. Sugiyama, Thomas H. Stix.
p. cm.

Includes bibliographical references and index.

ISBN 1-56396-377-9

1. Atmospheric sciences--Environmental aspects. 2. Plasma (Ionized gases)--Environmental aspects. 3. Energy policy--Environmental aspects. 4. Factory and trade waste--Environmental aspects. I. Manheimer, Wallace M., 1942-. II. Sugiyama, Linda E. III. Stix, Thomas Howard.

QC861.2.P53 1996
363.7--dc20

96-27719
CIP

| | |
|--|--------|
| 2.5 Component Electrical Processes and Possible Effects from Global Change..... | 32 |
| 2.5.1 Electrical Conductivity | 32 |
| 2.5.2 Thunderstorm Frequency and Global Change | 34 |
| 2.6 Conclusions | 35 |
| References..... | 37 |
| Chapter 3 Ionospheric Modification and Environmental Research in the Auroral Region | 41 |
| <i>Alfred Y. Wong, Michael McCarrick, Ralph F. Wuerker, Joel Villasenor, Bin Song, Helio Zwi, Glenn Rosenthal, Tuto Nakamura, Jacqueline Pau, Tetsuo Fukuchi, Davis D. Sentman, Roger Smith, Joseph Kan, Lung-Chih Tsai, and F. Tom Berkey</i> | |
| 3.1 Introduction | 41 |
| 3.2 Principle of Localized Interactions of Propagating EM Waves with Ionospheric Plasma | 44 |
| 3.2.1 Conversion from EM to ES Waves | 45 |
| 3.3 Characteristics of Ionospheric Plasmas | 46 |
| 3.3.1 Comparison between Equatorial and Auroral Ionospheric Conditions | 50 |
| 3.4 Experimental Methods | 51 |
| 3.4.1 Description of Facility and Antenna Array | 51 |
| 3.4.2 Diagnostics | 54 |
| 3.4.3 Space-Borne Diagnostics Complement the Ground-Based Diagnostics | 55 |
| 3.4.4 Method of Enhancing Wave Excitation by Coupling to Free-Energy Sources | 58 |
| 3.5 Conditions for Coupling to the Polar Ionosphere | 58 |
| 3.6 Selective Removal of Ions by Ion-Cyclotron Acceleration in the Polar Region | 64 |
| 3.6.1 Growth of EM Ion-Cyclotron Waves Driven by Field-Aligned Current | 73 |
| 3.6.2 Consideration of Power Requirements..... | 73 |
| Acknowledgments | 74 |
| References..... | 74 |

| | |
|--|---------|
| Chapter 4 Gyrotrons and Free-Electron Lasers for Atmospheric Sensing | 77 |
| <i>Wallace Manheimer</i> | |
| 4.1 Introduction | 77 |
| 4.2 Gyrotrons, Free-Electron Lasers, and Atmospheric Propagation | 78 |
| 4.2.1 Gyrotron Devices at Around 94 GHz | 78 |
| 4.2.2 Infrared Free-Electron Lasers..... | 89 |
| 4.3 Cloud Radar Studies with High-Power Gyrotrons..... | 92 |
| 4.3.1 Millimeter-Wave Cloud Radars | 93 |
| 4.3.2 Radar Scatter from Clouds | 93 |
| 4.3.3 Analysis of Radar Returns from Clouds | 95 |
| 4.3.4 High-Power Millimeter-Wave Atmospheric Probes | 97 |
| 4.4 Remote Sensing of Atmospheric Turbulence..... | 99 |
| 4.5 Remote Sensing of Trace Impurities in the Upper Atmosphere..... | 102 |
| 4.5.1 Trace-Element Determination by Radiometry | 103 |
| 4.5.2 Trace-Element Detection by Coherent Absorption Measurements | 107 |
| 4.5.3 Atmospheric Modification With High-Power Millimeter Waves | 111 |
| 4.6 Atmospheric Sensing with Free-Electron Lasers..... | 112 |
| 4.7 Conclusion | 114 |
| Acknowledgments | 115 |
| References..... | 115 |
| Chapter 5 Removing Chlorofluorocarbons from the Atmosphere with Lasers: A Second Look | 117 |
| <i>Thomas H. Stix</i> | |
| 5.1 Introduction | 117 |
| 5.2 Greenhouse Warming | 118 |
| 5.3 Ozone Depletion | 119 |
| 5.4 Trends in Ultraviolet Dose | 123 |
| 5.5 Destruction of CFC's by Electron Attachment | 124 |
| 5.6 Injection of Hydrocarbons into the Antarctic Stratosphere..... | 125 |
| 5.7 Laser Processing | 125 |
| 5.8 Ultimate Efficiency | 126 |
| 5.9 Electrical Power Costs for Infrared Multiphoton Dissociation | 127 |

| | |
|---|-----|
| 5.10 Systems Analysis..... | 128 |
| 5.11 Dissociation of CFC's by Ultraviolet Photons..... | 129 |
| 5.12 Dissociation of CFC's by Infrared Plus Ultraviolet Radiation | 132 |
| 5.13 Infrared Excitation of Molecular Vibration—Chirping the Laser..... | 136 |
| 5.14 CFC 11: An Exception?..... | 142 |
| 5.15 Collisional Relaxation..... | 142 |
| 5.16 Suppression of Stimulated Rotational Raman Scattering | 143 |
| 5.17 Conclusions | 145 |
| Acknowledgments | 145 |
| References..... | 146 |

Chapter 6 Convection Towers for Generating Electric Power and Reducing Air Pollution 149*Melvin L. Prueitt*

| | |
|--|-----|
| 6.1 Background | 149 |
| 6.2 The Problem | 149 |
| 6.3 The Solution | 150 |
| 6.4 Research at LASL..... | 153 |
| 6.5 Experimental Work..... | 156 |
| 6.6 Scavenging of Particulate Matter | 157 |
| 6.7 Scavenging of Gases..... | 158 |
| 6.8 Tower Effluents..... | 159 |
| 6.9 Electric Power Production | 160 |
| 6.10 Summary | 160 |
| References..... | 160 |

Part II . Energy Use and Conservation**Chapter 7 Recent Improvements in New Product Energy Efficiency.** 165
Arthur H. Rosenfeld and Lynn Price

| | |
|---|-----|
| 7.1 Introduction | 165 |
| 7.2 Automobiles..... | 166 |
| 7.3 Refrigerators | 168 |
| 7.4 Lighting | 168 |
| 7.4.1 Electronic Ballasts for Fluorescent Lamps | 170 |
| 7.4.2 Compact Fluorescent Lamps (CFL's) | 170 |

| | |
|---|-----|
| 7.5 Windows | 171 |
| 7.5.1 Windows from a Physics Perspective | 171 |
| 7.5.2 Low-Emissivity (Low-E) Windows | 173 |
| 7.5.3 Economics of Low-E Windows | 173 |
| 7.5.4 Spectrally Selective Windows—Plasma Frequency | 174 |
| 7.5.5 Advanced Windows and “Superwindows”..... | 176 |
| 7.6 Conclusion | 176 |
| Acknowledgments | 177 |
| References..... | 177 |

Chapter 8 Energy Conservation and Environmental Aspects of Lighting Plasmas 179
Gerald L. Rogoff

| | |
|--|-----|
| 8.1 Introduction | 179 |
| 8.2 Lamp Measures | 182 |
| 8.2.1 Lumen Output..... | 183 |
| 8.2.2 Efficacy | 184 |
| 8.2.3 Color-Rendering Index | 184 |
| 8.2.4 Color Temperature | 184 |
| 8.3 Low-Pressure Discharge Lamp Plasmas | 185 |
| 8.3.1 The Fluorescent Lamp | 185 |
| 8.3.2 The Low-Pressure Sodium Lamp..... | 194 |
| 8.3.3 Changes and Trends | 195 |
| 8.4 High-Intensity-Discharge (HID) Lamps | 198 |
| 8.5 Environmental Effects | 200 |
| 8.5.1 Mercury Content | 201 |
| 8.5.2 Mercury Disposal | 203 |
| 8.6 The Future | 204 |
| Acknowledgments | 205 |
| References..... | 205 |

Part III . Waste-Treatment: Prevention and Remediation**Chapter 9 Hot and Cold Plasma Processing of Waste** 209
Daniel R. Cohn

| | |
|------------------------|-----|
| 9.1 Introduction | 209 |
|------------------------|-----|

| | |
|--|-----|
| 9.2 High-Temperature Plasma Processing | 210 |
| 9.2.1 General Features | 210 |
| 9.2.2 Metal-Electrode-Plasma Furnace Applications | 212 |
| 9.2.3 Graphite-Electrode Arc-Plasma Furnace Applications | 214 |
| 9.2.4 Process Diagnostics..... | 215 |
| 9.2.5 Future Directions..... | 217 |
| 9.3 Low-Temperature, Nonequilibrium Processing | 217 |
| 9.3.1 General Approach..... | 217 |
| 9.3.2 Discharge Plasmas | 219 |
| 9.3.3 Electron-Beam-Generated Plasmas..... | 222 |
| 9.3.4 Future Directions..... | 227 |
| 9.4 Conclusions | 227 |
| Acknowledgments | 228 |
| References..... | 228 |

| | |
|---|------------|
| Chapter 10 Electron Scrubbing of Flue Gases to Remove Unwanted By-Products | 231 |
| <i>Ralph D. Genuario</i> | |
| 10.1 Electron-Beam Dry Scrubbing Process Description and History | 231 |
| 10.1.1 Background | 231 |
| 10.1.2 EBDS Process Description | 233 |
| 10.1.3 EBDS History | 235 |
| 10.2 e-SCRUB Requirements | 237 |
| 10.2.1 SO _x and NO _x Removal Requirements | 237 |
| 10.2.2 EBDS Cost Estimates and Technology Comparisons | 239 |
| 10.2.3 HPTA Technology versus Conventional Electron-Beam Guns..... | 244 |
| 10.3 HPTA Technology Development | 245 |
| 10.3.1 DOD Technology Overview..... | 245 |
| 10.3.2 HPTA Technology Overview..... | 247 |
| 10.3.3 Power-Conditioning Subsystem Description | 248 |
| 10.3.4 Electron-Beam Gun Design | 252 |
| 10.4 e-SCRUB Project Description | 256 |
| References..... | 258 |

| | |
|---|------------|
| Chapter 11 Processing of Hazardous Chemicals Using Silent-Electrical-Discharge Plasmas..... | 261 |
| <i>Louis A. Rosocha</i> | |
| 11.1 Introduction | 261 |
| 11.2 Electrical Considerations..... | 263 |
| 11.2.1 Discharge Mechanisms | 263 |
| 11.2.2 Electrical Properties of Silent Discharges | 267 |
| 11.3 Plasma Chemistry Considerations | 271 |
| 11.3.1 Radical Production | 274 |
| 11.3.2 Radical Utilization | 279 |
| 11.4 Process Chemistry | 282 |
| 11.5 Representative Experimental Results and Applications..... | 284 |
| 11.5.1 Equipment | 284 |
| 11.5.2 Results | 285 |
| 11.5.3 Applications..... | 288 |
| 11.6 Removal-Scaling Relationships and Figures of Merit | 291 |
| 11.6.1 Removal-Scaling Relationships | 291 |
| 11.6.2 Figure of Merit | 293 |
| 11.7 Conclusions | 294 |
| Appendix..... | 295 |
| Acknowledgments | 295 |
| References..... | 296 |
| Chapter 12 Accelerator-Based Systems for Plutonium Destruction and Nuclear-Waste Transmutation | 299 |
| <i>Edward D. Arthur</i> | |
| 12.1 Introduction | 299 |
| 12.2 Overview of ABC and ATW System Components..... | 300 |
| 12.3 Impacts of Material-Destruction Systems | 301 |
| 12.4 Choice of Transmutation-System Parameters | 305 |
| 12.4.1 Safety and Control | 305 |
| 12.4.2 Neutron Economy | 306 |
| 12.4.3 Fuel Cleanup | 306 |
| 12.5 Components of ABC and ATW Systems..... | 307 |
| 12.6 Value Provided by the Accelerator | 312 |
| 12.6.1 Safety and Control | 312 |

| | |
|---|------------|
| 12.6.2 Excess Neutrons for Transmutation of Long-Lived Fission Products | 314 |
| 12.6.3 Ease of Fuel-Cleanup Frequency | 315 |
| 12.7 Technology Status and Development | 316 |
| 12.8 Conclusions | 319 |
| References | 320 |
| Index | 321 |