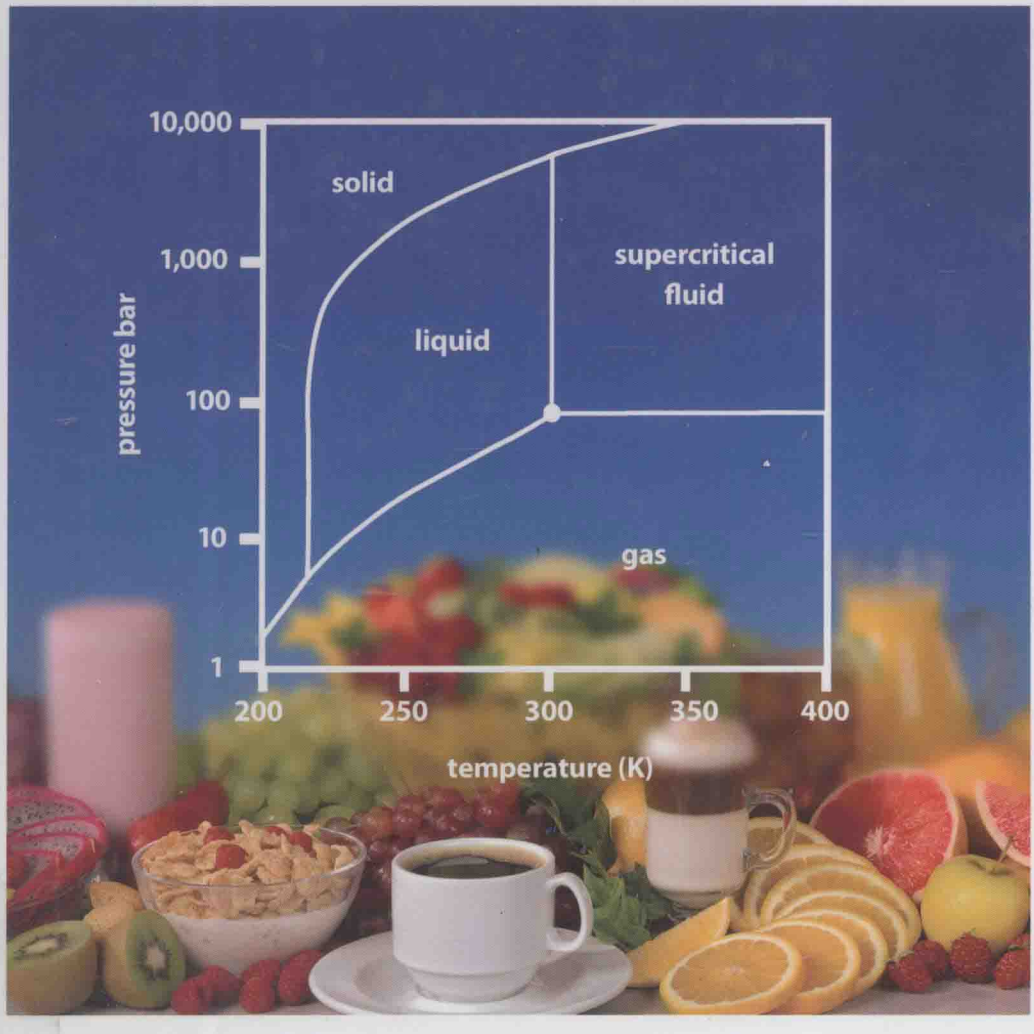
RSC Green Chemistry Series

Edited by Andrew Proctor

# Alternatives to Conventional Food Processing




RSC Publishing

# *Alternatives to Conventional Food Processing*

Edited by

**Andrew Proctor**
*Department of Food Science, University of Arkansas, USA*



RSC Publishing

RSC Green Chemistry No. 10

ISBN: 978-1-84973-037-2
ISSN: 1757-7039

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



Published by The Royal Society of Chemistry,
Thomas Graham House, Science Park, Milton Road,
Cambridge CB4 0WF, UK

Registered Charity Number 207890

For further information see our web site at www.rsc.org

Alternatives to Conventional Food Processing

**RSC Green Chemistry**

*Series Editor:*
James H Clark, *Department of Chemistry, University of York, York, UK*
George A Kraus, *Department of Chemistry, Iowa State University, Iowa, USA*

*Titles in the Series:*
1: The Future of Glycerol: New Uses of a Versatile Raw Material
2: Alternative Solvents for Green Chemistry
3: Eco-Friendly Synthesis of Fine Chemicals
4: Sustainable Solutions for Modern Economies
5: Chemical Reactions and Processes under Flow Conditions
6: Radical Reactions in Aqueous Media
7: Aqueous Microwave Chemistry
8: The Future of Glycerol: 2nd Edition
9: Transportation Biofuels: Novel Pathways for the production of Ethanol, Biogas and Biodiesel
10: Alternatives to Conventional Food Processing

*How to obtain future titles on publication:*
A standing order plan is available for this series. A standing order will bring delivery of each new volume immediately on publication.

*For further information please contact:*
Book Sales Department, Royal Society of Chemistry,
Thomas Graham House, Science Park, Milton Road, Cambridge,
CB4 0WF, UK
Telephone: +44 (0)1223 420066, Fax: +44 (0)1223 420247, Email: books@rsc.org
Visit our website at http://www.rsc.org/Shop/Books/

# *Preface*

The food industry is a large sector of the international business community, with food safety and food quality playing a vital role in maintaining profitability. Traditional thermal processing techniques have been effective in maintaining a safe food supply that is acceptable to consumers. However, increasing energy costs and the desire to purchase 'green' environmentally responsible products have been a stimulus for the development of alternative technologies. Furthermore, some products may undergo quality loss at high temperatures, which can be avoided by many alternative processing methods.

This book is intended to provide food industrialists, professional academics and graduate students with a review of the major alternative technologies that could be used to reduce energy costs while maintaining safety and quality. The introductory chapters provide the reader with an important discussion of the general principles of green technology underpinning the new technologies and the legal developments that are influenced by emerging new processing methods. The authors have all made significant contributions to their field and are well qualified to comment on the value and future significance of green food processing methods. It is hoped that this book will serve as an introduction for those interested in gaining an understanding of various 'green' alternative food processing technologies and the their role in the future of the food industry.

Andrew Proctor
University of Arkansas

RSC Green Chemistry No. 10
Alternatives to Conventional Food Processing
Edited by Andrew Proctor

Published by the Royal Society of Chemistry, www.rsc.org

# *Contents*


**Chapter 1** **Introduction to Green Chemistry** **1**
*James H. Clark*

1.1 Introduction 1
1.2 Resources for Re-manufacturing 5
1.3 Case Studies: Making the Most of Waste 7
1.3.1 Biofuels – Friend or Foe? 7
1.3.2 Extraction of Extractable Chemicals from Biomass 8
1.4 Conclusion 8
References 8

**Chapter 2** **Comparison of EU and US Law on Sustainable Food Processing** **11**
*Michael T. Roberts and Emilie H. Leibouitch*

2.1 Introduction 11
2.2 EU and US Law and Policy on Green Food Processing Issues 15
2.2.1 European Union 15
2.2.2 United States 25
2.3 Sustainability and the Emerging 'Green Processing' 34
2.3.1 Historical Development of the Concept of Sustainability 34
2.3.2 History of Sustainability Approach in the US and in the EU 37
2.3.3 Sustainable Agriculture in the US and in the EU 41
2.3.4 Sustainable Food Production in the US and in the EU 52



RSC Green Chemistry No. 10
Alternatives to Conventional Food Processing
Edited by Andrew Proctor



Published by the Royal Society of Chemistry, www.rsc.org

2.4 Private Standards 57
2.4.1 Outgrowth of Sustainability Movement 57
2.4.2 Applicability of Private Standards to the Food Sector in the EU and the US 59
2.4.3 Special Legal and Policy Challenges 63
2.4.4 International Trade Implications 68
2.5 Conclusion 71
2.5.1 Food Law Regulation in the US and the EU 71
2.5.2 Sustainability and Green Processing 73
2.5.3 Private Standards 74
References 75

**Chapter 3 Advances in Critical Fluid Processing 93**
*Jerry W. King, Keerthi Srinivas and Dongfang Zhang*

3.1 Introduction 93
3.2 Current Status of Supercritical Fluid Processing with $CO_2$ 94
3.3 Subcritical Fluids for Food Processing 97
3.4 Multi-fluid and Unit Operation Processing Options 109
3.5 Multi-phase Fluids for Sustainable and 'Green' Food Processing 116
3.6 Continuous Extraction by Coupling Expellers with Critical Fluids 122
3.7 Extraction *Versus* Reaction Using Pressurized Fluids 129
3.8 Conclusion 135
References 136

**Chapter 4 Supercritical Fluid Pasteurization and Food Safety 145**
*Sara Spilimbergo, Michael A. Matthews and Claudio Cinquemani*

4.1 Introduction 147
4.2 Supercritical Fluids and Green Technology 150
4.3 Current Issues in Food Pasteurization 150
4.3.1 Food Preservation 152
4.3.2 Nutritional Properties 152
4.3.3 Innovative Techniques 153
4.3.4 Packaging Material 153
4.3.5 Modified Atmosphere Packaging (MAP) 154
4.4 Mechanisms and Biochemistry of Microbial Deactivation 155
4.4.1 Pressure: Permeability, Membrane Disruption and Extraction 156
4.4.2 Temperature: Permeability and Extraction 156

4.4.3 pH: Cell Metabolism and Protein Activity 156
4.4.4 Fluid Flow and Contacting: Mass Transfer, Effect of Media and Kinetics of Pasteurization 157
4.5 Applications of Supercritical Fluids for Food Preservation 157
4.5.1 Biofilms 158
4.5.2 Modeling Approaches for High-pressure Microorganism Inactivation 160
4.5.3 Inactivation of Enzymes 160
4.5.4 Processes Based on Gases Other Than $CO_2$ 162
4.5.5 Subcellular Systems (Phages, Viruses, Proteins, Prions, Hazardous Macromolecular Substances) 163
4.5.6 Treatment of Solid Objects 164
4.5.7 Unsolved Problems to Date 165
4.5.8 Outlook and Discussion 166
4.5.9 Materials and Composites of Future Interest 166
4.6 Commercial Aspects 167
4.6.1 Equipment for $CO_2$ Technology 167
4.6.2 Patents 170
4.6.3 Commercialization 171
4.6.4 Economic Aspects 171
4.7 Conclusion 173
References 174

**Chapter 5 Membrane Separations in Food Processing 184**
*Koen Dewettinck and Thien Trung Le*

5.1 Types of Membrane Separation Processes 185
5.1.1 Pressure-driven Membrane Separations 185
5.1.2 Other Types of Membrane Separation Processes 186
5.2 Separation Characteristics 187
5.2.1 Filtration Modes 187
5.2.2 Membrane Separation Parameters 188
5.3 Concentration Polarization and Membrane Fouling 189
5.3.1 Concentration Polarization 189
5.3.2 Membrane Fouling 190
5.4 Membrane Characteristics and Membrane Modules 192
5.4.1 Membrane Characteristics 192
5.4.2 Membrane Modules 193
5.5 Enhancement of Membrane Separation Performance 198
5.5.1 Optimization of Operational Parameters 198
5.5.2 Effects of Feed Properties 203
5.5.3 Membrane Selection and Surface Modification 205

5.5.4 Modification of Membrane Module Configuration 205
5.5.5 Flow Manipulation 215
5.5.6 Applications of External-body Forces 221
5.5.7 Other Techniques 226
5.5.8 Selection of the Techniques 227
5.6 Membrane Cleaning and Sanitation 228
5.7 Comparison between Membrane Separations and Corresponding Traditional Technologies 229
5.7.1 General Applications and Technological Advantages of Membrane Separations 229
5.7.2 Economic Aspects of Membrane Processing Applications 231
5.8 Applications of Membrane Separations in the Food Industry 232
5.8.1 Membrane Processes in the Dairy Industry 232
5.8.2 Membrane Processes in the Brewing Industry 235
5.8.3 Membrane Processes in the Winemaking Industry 236
5.8.4 Membrane Processes in the Production of Fruit and Vegetable Juices 237
5.8.5 Membrane Processes in the Sugar Industry 237
5.8.6 Membrane Processes in the Production of Soy Ingredients and Products 238
5.8.7 Other Applications in the Food Industry 238
5.9 Conclusions and Perspectives 239
Acknowledgements 240
References 240

**Chapter 6 High Hydrostatic Pressure Food Processing 254**
*Stephanie Jung, Carole Tonello-Samson and Marie de Lamballerie*

6.1 Introduction 254
6.1.1 Rationale for the Interest in High-pressure Processing 254
6.1.2 Brief Description of Processing Steps and Concept of Adiabatic Heating 255
6.1.3 Is HPP a Green (Environmentally Friendly) Technology? 257
6.2 HPP as an Efficient Tool for Food Microbial Safety and Shelf-life Extension 258
6.2.1 Food Safety 258
6.2.2 Shelf-life 260

6.3 Pressure-induced Modifications of Physico-chemical Properties of Food Compounds 262
6.3.1 Water 263
6.3.2 Proteins 263
6.3.3 Lipids 266
6.3.4 Carbohydrates 266
6.3.5 Nutritional Compounds 267
6.4 Quality Attributes of Pressurized Food Products 267
6.4.1 Textural and Rheological Properties 267
6.4.2 Functional Properties 276
6.4.3 Color 277
6.4.4 Flavor 280
6.4.5 Allergenicity/Antigenicity 281
6.5 Pressure-assisted Extraction of Food Components 281
6.6 Commercial Applications of HPP 282
6.6.1 Fruit and Vegetable Products 287
6.6.2 Meat Products 288
6.6.3 Seafood 289
6.6.4 Dairy Products 290
6.7 HPP Industrial Equipment 290
6.7.1 Design 290
6.7.2 Size and Output 294
6.7.3 Investment and Processing Costs 295
6.8 Final Remarks 296
References 296

**Chapter 7 Ohmic Heating of Foods 307**
*James G. Lyng and Brian M. McKenna*

7.1 Introduction 307
7.2 Basic Principle of Ohmic Heating 308
7.2.1 The Electrical Circuit 308
7.2.2 Mechanism of Ohmic Heating 309
7.2.3 Factors Influencing Heat Generation Rate 310
7.3 Electrical Conductivity of Foods 311
7.4 Microbial Inactivation During Ohmic Heating 311
7.5 Physical and Chemical Changes to Foods During Ohmic Heating 312
7.5.1 Nutritional Effects 312
7.5.2 Protein Coagulation/Denaturation 312
7.6 Non-preserving Thermal Processes 313
7.6.1 Parboiling 313
7.6.2 Blanching 314
7.6.3 Thawing 315
7.7 Ohmic Sterilization 317

7.7.1 Technological Challenges in Validating Ohmic Sterilization Procedures 317
7.7.2 Temperature Measurement 317
7.7.3 Modelling of Ohmic Sterilization 317
7.7.4 Markers 318
7.7.5 Conductivity Differences 318
7.7.6 Solid–Liquid Flow 318
7.7.7 Commercial Uptake 318
7.8 Ohmic Dehydration 319
7.9 Specific Food Products 320
7.9.1 Meat 320
7.9.2 Fish 321
7.9.3 Milk 323
7.9.4 Fruit and Fruit Juices 324
7.9.5 Egg 325
7.9.6 Vegetables 326
7.10 Economics of Ohmic Processing 327
7.11 Ohmic Heater Control Options 328
7.11.1 Control of Electricity Supply During Ohmic Heating 328
7.11.2 Control of the Extent of Pasteurization/ Cooking 329
7.11.3 Packaging for Ohmic Processing 329
7.12 Modelling 330
7.12.1 General Heating Theory 330
7.12.2 Model Development 330
7.12.3 Prediction of Temperature Profiles in Liquid Foods 331
7.12.4 Prediction of Temperature Profiles in Liquid Foods Containing Particulates 331
7.12.5 Modelling the Fouling Behaviour of Ohmic Heaters 333
7.12.6 Other Factors 333
References 334

**Chapter 8 Aqueous Enzymatic Oil Extraction from Seeds, Fruits and Other Oil-rich Plant Materials 341**
*Robert A. Moreau*

8.1 Introduction 341
8.2 Conventional Extraction of Plant Oils *Via* Pressing and/or Hexane Extraction 343
8.3 Some Anatomical Differences Between Oil-rich Fruits and Oil-rich Seeds 345

8.4 Aqueous and Aqueous Enzymatic Methods to Extract Oil from Oil-rich Fruits such as Olives, Avocados and Palm 347
8.5 Aqueous and Aqueous Enzymatic Methods to Extract Oil from Corn Germ 350
8.6 Aqueous and Aqueous Enzymatic Methods to Extract Oil from Soybeans 355
8.7 Aqueous and Aqueous Enzymatic Methods to Extract Oil from Rice Bran 355
8.8 Aqueous and Aqueous Enzymatic Methods to Extract Oil from Peanuts 355
8.9 Aqueous and Aqueous Enzymatic Methods to Extract Oil from Rapeseed and Canola 355
8.10 Aqueous and Aqueous Enzymatic Methods to Extract Oil from Sunflower 357
8.11 Aqueous and Aqueous Enzymatic Methods to Extract Oil from Coconuts 357
8.12 Aqueous and Aqueous Enzymatic Methods to Extract Oil from Other Oil-rich Plant Materials 358
8.13 Aqueous Microemulsion Methods to Extract Oil from Peanuts, Sunflower, Canola/Rapeseed and Corn Germ 359
8.14 Conclusions 359
Disclaimer 361
References 361

**Chapter 9 High-intensity Pulsed Light Food Processing 367**
*Carmen I. Moraru*

9.1 Fundamentals of Pulsed Light Technology 367
9.1.1 Components of Pulsed Light Systems 367
9.1.2 Spectral and Energetic Characteristics of Pulsed Light 369
9.2 Microbial Inactivation Using Pulsed Light 371
9.2.1 Mechanisms of Inactivation 371
9.2.2 Factors That Affect Microbial Inactivation By Pulsed Light 372
9.2.3 Microbial Inactivation Kinetics in Pulsed Light Treatment 376
9.3 Applications of Pulsed Light Treatment 377
9.3.1 Pulsed Light Treatment of Liquids 377
9.3.2 Pulsed Light Treatment of Surfaces 378
9.3.3 Other Applications of Pulsed Light Treatment 380

9.4 Commercial Pulsed Light Systems 381
9.5 Conclusions 382
References 382

**Chapter 10 Ultrasonic Food Processing** **387**
*Timothy J. Mason, Larysa Paniwnyk, Farid Chemat and Maryline Abert Vian*

10.1 Introduction 387
10.2 Fundamentals of Ultrasound for Food Processing 388
10.2.1 Power Ultrasound in Liquid Systems 388
10.2.2 Power Ultrasound in Gaseous Systems 392
10.3 Applications of Ultrasound in Food Processing 392
10.3.1 Filtration 392
10.3.2 Defoaming 393
10.3.3 Degassing 394
10.3.4 Depolymerization 395
10.3.5 Cooking 396
10.3.6 Demoulding and Extrusion 397
10.3.7 Cutting 399
10.3.8 Freezing and Crystallization 400
10.3.9 Defrosting/Thawing 401
10.3.10 Drying 402
10.3.11 Tenderizing Meat Products 403
10.3.12 Brining, Pickling and Marinating 404
10.3.13 Sterilization/Pasteurization 405
10.3.14 Extraction 406
10.3.15 Emulsification/Homogenization 406
10.3.16 Miscellaneous Effects 407
10.4 Conclusion 407
References 407

**Chapter 11 Microwave Food Processing** **415**
*Sandrine Perino-Issartier, Jean-François Maingonnat and Farid Chemat*

11.1 Introduction 415
11.2 Theory 416
11.2.1 Microwave Heat Transfer 416
11.2.2 Instrumentation 418
11.2.3 Interaction of Microwave Energy with Biological Material 420
11.3 Drying 421
11.4 Thawing and Tempering 425

11.5 Blanching 428
11.6 Baking 431
11.7 Continuous Pasteurization and Sterilization of Liquid Food 434
11.8 Microwave Extraction Techniques 437
11.8.1 Microwave-assisted Solvent Extraction (MASE) 437
11.8.2 Microwave-assisted Distillation (MAD) 438
11.8.3 Microwave Hydrodiffusion and Gravity (MHG) 440
11.8.4 Main Applications of Microwave-assisted Extraction 441
References 444

**Subject Index** **459**

CHAPTER 1

# *Introduction to Green Chemistry*

JAMES H. CLARK

Green Chemistry Centre of Excellence, University of York, York, UK, YO10 3HW

## 1.1 Introduction

This brief chapter provides readers who are unfamiliar with 'green technology' with a broad understanding of 'green principles' to better appreciate the social, economic and technical context that necessitate the development of alternative food processing techniques, that reduce energy requirements and/or organic 'chemical' solvent use. Life-cycle analysis is also introduced as a key concept in evaluating the sustainability of any green technology that uses alternative fuels, or reduces energy use, relative to established technology. The issue of biofuels is explored and supercritical extraction briefly discussed as an example of green transformation.

Developing alternative technologies and products are essential to move the food industry, and other industries, towards sustainable processing and to reduce commercial energy use and thereby responsibly preserve local and global environments. This activity is called Green Chemistry, Green Engineering or Sustainable Design[1] and requires input from various scientific, engineering, technological, environmental, economic and legal disciplines. It is influenced by multiple drivers which affect the creation of new green technologies, which are outlined in Figure 1.1.[2]

Green chemistry/technology involves the sustainable manipulation of chemicals and materials to value-added products, and therefore involves both new processes and products. The principles of green chemistry were first outlined in

RSC Green Chemistry No. 10
Alternatives to Conventional Food Processing
Edited by Andrew Proctor

Published by the Royal Society of Chemistry, www.rsc.org

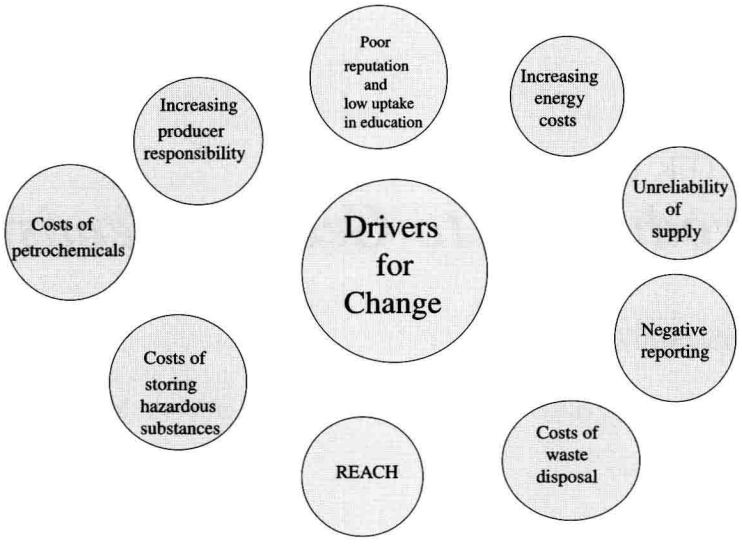



**Figure 1.1** Drivers for change – and green chemistry.

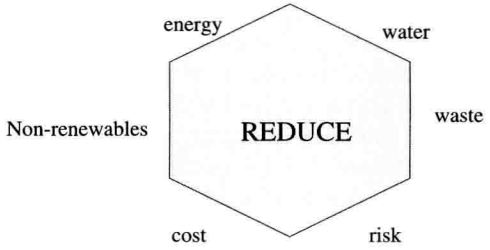



**Figure 1.2** Green chemistry reductions.

the 1990's.[3] However, it can also be considered as simply a means of maximizing the efficient use of resources and achieving cost savings, while minimizing negative human and environmental impact (Figure 1.2).[4] Green chemistry requires new, low environment impact technologies to reduce energy use, facilitate greater use of catalysis and environmentally benign processing and avoidance of harmful organic solvents. Furthermore, it also involves reducing the number of processing steps in industrial manufacturing to obtain the same products in fewer processing steps with less energy and waste materials.[5]

Green engineering thus requires the application of fundamental engineering concepts and practices to reduce the environmental impact of current manufacturing practices.[6] The United States Environmental Protection Agency describes this as the design, commercialization and use of processes and