

Table of Contents

Preface	i
Contributors	ii
Acknowledgments.....	iv
Reviewers.....	vi
Chapter Authors	ix
Executive Summary	xxi
Synopsis.....	xxii
Introduction.....	xxiii
Goals of Volume 2	xxiv
Scenarios and Data Inputs.....	xxiv
Land Allocation and Management	xxvii
Greenhouse Gas Emissions, Soil Carbon, and Fossil Energy Consumption	xxix
Water Quality (Agriculture)	xxix
Water Quality (Forestry)	xxx
Water Quantity (Forestry).....	xxx
Water Consumption Footprint (Agriculture and Forestry)	xxxii
Air Pollutant Emissions (Agriculture and Forestry).....	xxxii
Biodiversity (Agriculture).....	xxxii
Biodiversity (Forestry).....	xxxii
Qualitative Analysis of Environmental Effects of Algae Production.....	xxxiii
Climate Sensitivity of Feedstock Productivity	xxxiii
Synthesis and Conclusions	xxxiv
References	xxxvi
1.0 Introduction.....	1
1.1 Background.....	2
1.2 Objectives	3
1.2.1 Scenarios	3
1.2.2 Research Questions	5

1.3 Environmental Indicators of Bioenergy Sustainability 5

1.4 Scope and Scale 7

1.5 Supply Constraints in *BT16* volume 1 11

1.6 Limitations 12

1.7 *BT16* volume 2 Organization 13

1.8 References 14

2.0 *BT16* Feedstock Assessment Methods and Select Scenarios 17

2.1 Introduction 18

2.2 Agricultural Feedstocks..... 19

 2.2.1 Model Inputs, Assumptions, and Constraints 19

 2.2.2 Scenarios..... 23

2.3 Forestry Feedstocks..... 25

 2.3.1 Model Inputs, Assumptions, and Constraints 25

 2.3.2 Scenarios..... 28

2.4 Environmental Effects Assessment 29

 2.4.1 Farmgate and Landing Supplies..... 29

 2.4.2 Attribution..... 30

 2.4.3 Inter-Annual Crop Transition Estimates 31

 2.4.4 Supplies Delivered to Biorefineries 31

2.5 References..... 33

3.0 Land Allocation and Management: Understanding Land-Use Change (LUC) Implications under *BT16* Scenarios..... 37

3.1 Introduction 38

 3.1.1 Objectives 38

 3.1.2..... The Importance of LUC and Related Indicators 39

3.2 Research Goals Guide Choices for Model Parameters, Assumptions, and Definitions..... 39

 3.2.1 The Differences between *BT16* and Analyses that Focus on LUC 40

 3.2.2 Concepts and Definitions Relevant to LUC 40

 3.2.3 LUC and Biomass from Forestland..... 41

3.3 Indicators to Capture LUC Effects..... 42

3.4 LUC and Agricultural Land: Cropland and Pasture.....	43
3.4.1 Changes in Agricultural Land Management under <i>BT16</i> Scenarios.....	46
3.4.2 Land Input Assumptions Drive LUC Estimates	48
3.4.3 Agricultural Land Allocated to Biomass Crops	51
3.5 LUC Modeling.....	53
3.5.1 How <i>BT16</i> Relates to Concerns about ILUC.....	54
3.5.2 <i>BT16</i> Results in Context of Other LUC Studies.....	55
3.6 Discussion	57
3.6.1 Land for Biomass Crops in Context of Historical Trends	57
3.6.2 Implications and Potential Benefits of <i>BT16</i> LUC	59
3.6.3 Uncertainties and Limitations in LUC Assessments	60
3.7 Future Research.....	63
3.8 Conclusions	64
3.9 References.....	67
Appendix 3-A: Terminology, Definitions, and Sources.....	75
3A.1 Issues of Initial Land Cover Classification are Complex and have Huge Influence on LUC Analysis.....	76
3A.2 Reference Case Considerations for LUC Modeling	79
3A.3 <i>BT16</i> LUC Constraints and Land Allocation Scenarios	80
References	81
4.0 Fossil Energy Consumption and Greenhouse Gas Emissions, Including Soil Carbon Effects, of Producing Agriculture and Forestry Feedstocks.....	85
4.1 Introduction	86
4.2 Methods.....	87
4.2.1 Material and Energy Consumption during Feedstock Production	87
4.2.2 Estimation of SOC Changes.....	89
4.2.3 Changes in Aboveground Carbon.....	95
4.2.4 Representative Bioeconomy Cases	96
4.3 Results	97
4.3.1 Energy Consumption and GHG Emissions Associated with Forestry and Agricultural Operations and Logistics	97
4.3.2 GHG Emissions from SOC Changes on Agricultural Lands	107

4.3.3 Spatial GHG Emissions Including Agricultural and Forestry Operations, Logistics and Preprocessing, and SOC Changes110

4.3.4 Reduction in GHG Emissions for Representative Bioeconomy Cases115

4.4 Discussion116

4.4.1 Implications of Results116

4.4.2 Uncertainties and Limitations117

4.5 Summary and Future Research118

4.6 References119

Appendix to Chapter 4 – Fossil Energy Consumption and Greenhouse Gas Emissions of Producing Agriculture and Forestry Feedstocks121

Appendix 4-A: Detailed Methodology.....121

Calculating County-Level Greenhouse Gas Emissions and Fossil Energy Consumption121

Woody Feedstocks (Willow, Eucalyptus, Poplar, and Loblolly Pine)126

Forestry-Derived Feedstocks126

Feedstock Logistics126

References129

Appendix 4-B: Sustainability of Extracting Primary Forest Residue Biomass131

4B.2 Research on Site Productivity Following Biomass Harvests131

4B.3 Compaction.....132

4B.4 References.....135

5.0 Water Quality Responses to Simulated Management Practices on Agricultural Lands Producing Biomass Feedstocks in Two Tributary Basins of the Mississippi River139

5.1 Introduction140

5.1.1 Cellulosic and Perennial Feedstocks141

5.1.2 Conservation Practices141

5.1.3 Co-Optimizing Production and Water Quality142

5.2 Scope of Assessment.....142

5.3 Methods143

5.3.1 Environmental Indicators.....144

5.3.2 SWAT Implementation145

5.3.3 Conservation Practices151

5.4 Results153

5.4.1 Arkansas-White-Red River Basin.....	153
5.4.2 Iowa River Basin.....	169
5.5 Summary	176
5.6 References.....	178
6.0 Water Quality Response to Forest Biomass Utilization.....	183
6.1 Introduction	184
6.1.1 Sediment, Nitrate, and TP	185
6.1.2 Management Intensity and BMPs	186
6.2 Methods.....	187
6.2.1 Scope of Assessment.....	187
6.2.2 Description of Water Quality Response Modeling.....	188
6.3 Results	191
6.3.1 Baseline Scenario ML 2017.....	197
6.3.2 ML 2040 and HH 2040.....	198
6.4 Discussion	198
6.5 Uncertainties and Limitations	201
6.6 Summary and Future Research.....	202
6.7 References.....	204
7.0 Impacts of Forest Biomass Removal on Water Yield across the United States	211
7.1 Introduction.....	212
7.2 Methods	213
7.2.1 Scope of Assessment	214
7.2.2 Description of the Ecohydrological Model (WaSSI).....	216
7.3 Results.....	218
7.3.1 Potential Maximum Impacts of Forest Removal on Water Yield by County	218
7.3.2 Impacts of Forest Removal on Water Yield by County under Three Scenarios.....	221
7.3.3 Seasonal Response to Biomass Removal	227
7.4 Discussion.....	228
7.4.1 Implications of Modeling Results.....	229
7.4.2 Uncertainties and Limitations.....	229

7.5 Summary and Future Research..... 229

7.6 References 231

8.0 Water Consumption Footprint of Producing Agriculture and Forestry Feedstocks 235

8.1 Introduction 236

8.2 Methods..... 237

 8.2.1 Scope of Assessment..... 237

 8.2.2 Scenarios..... 239

 8.2.3 Description of Water Footprint Accounting for Crops, Grasses, and Forest Resources..... 240

 8.2.4 Data Sources 241

 8.2.5 Description of Water Footprint Implementation..... 242

8.3 Results and Discussion 243

 8.3.1 Water Footprint of the Biomass Production Scenarios 243

 8.3.2 Impact on Groundwater Irrigation..... 250

8.4 Uncertainties and Future Work..... 254

8.5 References..... 255

Appendix 8-A 260

8A.1 Crops 260

8A.2 Perennial Grasses 261

8A.3 Wood from Forests 263

8A.4 References..... 266

9.0 Implications of Air Pollutant Emissions from Producing Agricultural and Forestry Feedstocks..... 269

9.1 Introduction 270

9.2 Methods..... 272

 9.2.1 Scope of the Analysis..... 272

 9.2.2 Description of Feedstock Production Emissions to Air Model (FPEAM)..... 275

9.3 Results 285

 9.3.1 Comparison of Emissions per dt of Biomass by Feedstocks 285

 9.3.2 Emissions Contribution by Activity Category..... 290

 9.3.3 Comparison of Estimated Emissions Inventory to the NEI and NAAQS NAAs 294

9.3.4 Additional Discussion	304
9.4 Discussion	307
9.4.1 Implication of Results	307
9.4.2 Limitations of This Study	309
9.5 Summary and Future Work.....	313
9.6 References	316
Appendix 9-A	321
9A.1 Key Equipment Activity Assumptions.....	321
9A.2 Key Emission Modeling Assumptions.....	324
9A.3 Supplemental Results	350
9A.3.1 SO _x , NO _x , and CO	350
9A.4 References.....	361
10.0 Simulated Response of Avian Biodiversity to Biomass Production	367
10.1 Introduction.....	368
10.2 Scope of Assessment	369
10.3 Methods	370
10.3.1 B716 LULC Allocation.....	371
10.3.2 Overview	372
10.3.3 Species Distribution Modeling.....	374
10.3.4 Modeling Occupancy in Extant LULC Classes.....	374
10.3.5 Modeling Occupancy in Biomass Crops as LULC Classes	375
10.3.6 Accounting for Minimum Area Requirements	380
10.3.7 Projecting Changes in Richness.....	381
10.4 Results.....	381
10.4.1 Species Distribution Modeling.....	381
10.4.2 Minimum Habitat Area	382
10.4.3 Projected Changes in Richness under BC1 2040 Scenario.....	382
10.5 Discussion.....	385
10.6 Future Directions.....	386
10.7 References	387
Appendix 10-A	392

11.1 Background	398
12.0 Forest Biodiversity and Woody Biomass Harvesting	398
11.2 Methods	401
11.2.1 Scope of Assessment	402
11.2.2 Relevant ForSEAM Assumptions	403
11.3 Results.....	403
11.3.1 Conterminous United States.....	404
11.3.2 South Region	410
11.3.3 North Central Region.....	418
11.3.4 Northeast	422
11.3.5 Pacific Northwest Region	426
11.3.6 Inland West Region.....	432
11.4 Discussion.....	436
11.4.1 Implications of Results	436
11.4.2 Uncertainties and Limitations	437
11.5 Summary and Future Research	438
11.6 References	440
12.0 Qualitative Analysis of Environmental Effects of Algae Production	449
12.1 Introduction.....	450
12.2 Scenarios.....	450
12.2.1 Environmental Indicators for Algae	452
12.2.2 Indicators and Indices for Water Quantity—The Importance of Regional Context	453
12.3 Methods.....	456
12.3.1 Scope of Assessment	457
12.4 Results and Discussion.....	458
12.4.1 GHG Emissions	458
12.4.2 Water Quantity	467
12.4.3 Water Quality.....	486
12.4.4 Other Environmental Indicators	487
12.5 Summary and Future Research.....	489
12.6 References	491

Appendix 12-A: Water Resource Indices	501
References	505
Appendix 12-B: Environmental Flow Requirements	506
References	510
Appendix 12-C: Contributions of Sectors to Total Consumptive Water Use	512
References	514
Appendix 12-D: Comparison of Water Use by Selected Terrestrial Crops and Microalgae Water Use—Geographic Analysis.....	515
References	517
13.0 Climate Sensitivity of Agricultural Energy Crop Productivity	519
13.1 Introduction.....	520
13.2.1 Scope of Assessment	521
13.2.2 Description of Modeling Approach.....	521
13.3 Results	526
13.3.1 National-Level Results.....	526
13.3.2 County-Level Results.....	528
13.4 Uncertainties and Limitations	544
13.5 Discussion	545
13.6 Summary and Future Research	545
13.7 References	546
Appendix to Chapter 13: Additional Details on Model Validation	551
13A.1. Validation Statistics for Bayesian Models	551
13A.2. Comparison of Worldclim and PRISM Historical Climatologies.....	553
14.0 Synthesis, Interpretation, and Strategies to Enhance Environmental Outcomes	555
14.1 Introduction	556
14.1.1 Synthesis and Interpretation of Results	557
14.1.2 Uncertainties and Limitations	559
14.2 Enhancing Environmental Outcomes: Strategies Identified in this Report.....	560

14.2.1 Supply Constraints in Biomass Resource Assessments 560

14.2.2 Mitigation Strategies..... 561

14.3 Enhancing Environmental Outcomes: Going Beyond Analyses in this Report 563

14.3.1 Best Management Practices563

14.3.2 Landscape Design 564

14.3.3 Precision Agriculture567

14.3.4 Multipurpose Biomass Production and Removal.....570

14.3.5 Monetary Strategies 572

14.4 Looking Forward and Future Research Needs572

14.4.1 Summary of Key Research Needs Identified in *BT16* Volume 2 572

14.4.2 Integrated Consideration of Environmental Indicators 574

14.4.3 Integration across Environmental, Social, and Economic Effects 575

14.4.4 Concluding Thoughts..... 576

14.5 References577

Glossary of Key Terms..... 585

Glossary of Key Terms..... 586

List of Acronyms 598