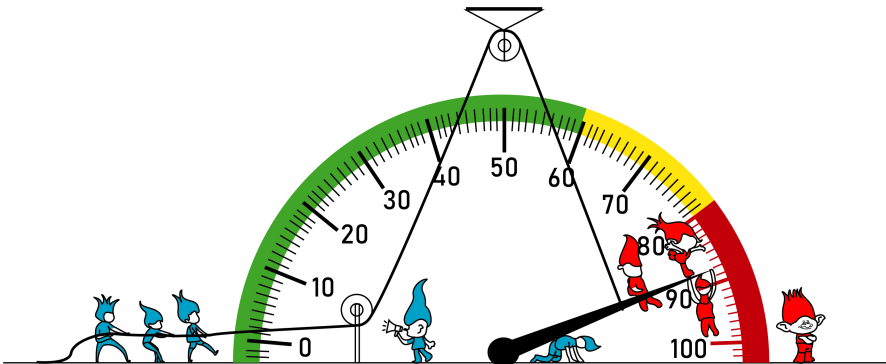


# Global Climate Change

## The Pragmatist's Guide to Moving the Needle



Ivo Welch and Bradford Cornell

Copyright Ivo Welch, Brad Cornell, 2022.

This book was typeset in Lua<sup>A</sup>T<sub>E</sub>X.

Primary Font: Charter, 12pt.

Highlight Fonts: LMSans, Helvetica.

Primary Source of Cartoons: [cartoonstock.com](http://cartoonstock.com).

Primary Graphics Generator: R<sub>L</sub>Language.

Front Cover Design: [Midul Hasan](#) and Ivo Welch.

This book is accompanied by a free online version at <https://climate-change.world>, which has [hyperlinked](#) references (merely underdotted in the printed version) and fully colorized graphs.

# Contents

	<b>The Physical Problem</b>	<b>1</b>
<b>1</b>	<b>Humanity</b>	<b>3</b>
1	Capitalism and Population . . . . .	4
2	The Population Explosion . . . . .	5
3	Regional Population Variation . . . . .	8
4	Rich and Poor: OECD and non-OECD . . . . .	9
5	Population Taboos . . . . .	11
6	What Now? . . . . .	12
7	We are a Problem . . . . .	14
<b>2</b>	<b>Energy</b>	<b>17</b>
1	How To Measure Power and Energy . . . . .	18
2	Where Does All Our Energy Go? . . . . .	26
3	Rich and Poor Today . . . . .	28
4	The Future . . . . .	32
5	Clean and Dirty Energy . . . . .	38
6	Important Details and Clarifications . . . . .	42
7	The Situation Today . . . . .	45
<b>3</b>	<b>Greenhouse Gases</b>	<b>49</b>
1	Measuring Human Emissions . . . . .	50
2	Earth's Natural Carbon Cycle . . . . .	58
3	Accumulating Human Emissions . . . . .	61
4	The Balance Sheet . . . . .	65
5	Growth in Human CO <sub>2</sub> Emissions . . . . .	69
6	Energy and Emissions . . . . .	72
7	The Kaya Components . . . . .	77
8	Reducing the World's Emissions . . . . .	85

<b>4</b>	<b>Climate Science</b>	<b>89</b>
1	Climate Versus Weather . . . . .	90
2	The Global Thermostat . . . . .	96
3	The Temperature Record . . . . .	99
4	Greenhouse Gases and Temperature . . . . .	111
5	Scientific Agreement and Disagreement . . . . .	114
6	Were the Models Wrong in the Past? . . . . .	122
<b>5</b>	<b>A Warmer Future</b>	<b>129</b>
1	The Expected Warming Path . . . . .	131
2	The Expected Warming Harm . . . . .	136
3	Inevitable Change and Associated Harm . . . . .	142
4	Temperature Change Summary . . . . .	145
5	The Well-Known Unknowns . . . . .	147
6	The Less-Known Unknowns . . . . .	148
7	Appropriate Perspectives . . . . .	154
8	Planetary Roulette, Anyone? . . . . .	158
	<b>The Social Problem</b>	<b>163</b>
<b>6</b>	<b>A Crash Course in Economics</b>	<b>165</b>
1	Human Self-Interest and Free Riding . . . . .	166
2	The Tragedy of the Commons . . . . .	169
3	When Should Governments Intervene? . . . . .	172
4	Practical Problems of Pollution Taxes . . . . .	181
5	Margins, Costs, and Scale . . . . .	184
6	The Economics of Innovation . . . . .	189
7	Moving the Needle Now . . . . .	191

<b>7</b>	<b>Modeling The World Economic Impact</b>	<b>193</b>
1	An Economic Sketch of Earth . . . . .	194
2	What Goes In and What Comes Out? . . . . .	196
3	What is the Scientific Consensus? . . . . .	201
4	What are the Right Model Parameters? . . . . .	206
5	What Else Should Be in the Model? . . . . .	212
6	What Have We Learned from IAMs? . . . . .	214
<b>8</b>	<b>The Wrong Questions</b>	<b>219</b>
1	Problems, Choices, and Outcomes . . . . .	220
2	Can We Go It Alone? . . . . .	222
<b>9</b>	<b>Unrealistic Approaches</b>	<b>231</b>
1	Why It's So Difficult . . . . .	233
2	Why A Global CO <sub>2</sub> Tax is Unrealistic . . . . .	235
3	Why Climate Treaties are Unrealistic . . . . .	239
4	Why Corporate Solutions are Unrealistic . . . . .	249
5	Why Divestment Makes No Sense . . . . .	251
6	Why Individual Solutions Are Doomed . . . . .	253
7	Is Climate Change About Social Justice? . . . . .	260
<b>10</b>	<b>Realistic Approaches</b>	<b>267</b>
1	Basic Requirements for Success . . . . .	268
2	Enact Local Fossil-Fuel Taxes! . . . . .	270
3	Promote Technological Change! . . . . .	278
4	Recommendable Activism . . . . .	281

	<b>The Technology Problem</b>	<b>285</b>
<b>11</b>	<b>Leaving Fossil Fuels</b>	<b>287</b>
1	Ongoing Growth . . . . .	288
2	Fossil Fuel Advantages . . . . .	289
3	Hydrogen . . . . .	291
4	Nuclear Power . . . . .	293
5	Batteries . . . . .	297
6	How To Read Technology Forecasts . . . . .	299
7	The Politics of Defending Fossil Fuels . . . . .	300
8	The War on Climate-Change . . . . .	305
<b>12</b>	<b>Electricity</b>	<b>311</b>
1	Why Electricity? . . . . .	311
2	Not All Electricity Is the Same . . . . .	313
3	Basic Electricity Provision . . . . .	314
4	Base, Intermittent, Dispatch Power . . . . .	319
5	Technologies For Generation . . . . .	321
6	Tech for Storing Electric Energy . . . . .	331
7	Transmitting Electricity . . . . .	342
8	Earth's Economic Energy Problem . . . . .	345
9	The Business Perspective . . . . .	349
10	The Role of The Market . . . . .	352
11	Current Power Plans and Forecasts . . . . .	355
12	Reliability . . . . .	357
<b>13</b>	<b>Beyond Electrification</b>	<b>365</b>
1	Hydrogen . . . . .	366
2	Industrial Heat . . . . .	371
3	Agriculture . . . . .	373
4	More Methane Problems . . . . .	380
5	Construction and Efficiency . . . . .	385
<b>14</b>	<b>Remediation and Geoengineering</b>	<b>389</b>
1	The Social Cost of CO <sub>2</sub> (Yet Again) . . . . .	391
2	CO <sub>2</sub> Removal . . . . .	393
3	Solar Radiation Management . . . . .	401

	<b>The Transitioning Problem</b>	<b>407</b>
<b>15</b>	<b>Making It Happen</b>	<b>409</b>
1	What Can Countries Do? . . . . .	412
2	What Can Individuals Do? . . . . .	432
App. A	Some Exciting Green Tech . . . . .	440
App. B	Recommendations By Others . . . . .	442
	<b>Appendix</b>	<b>447</b>
	<b>Crib Sheet — Summary of Facts</b>	<b>449</b>





## THANKS

Many people have helped us with advice on subjects that we have struggled with. This does not necessarily mean that they endorsed our final perspectives. We want to thank especially the following:

David Archer, University of Chicago  
John Cochrane, Stanford University  
Andrew Dessler, Texas A&M University  
Maynard Holt, Tudor, Pickering, Holt & Co.  
Peter Keller, Berkeley Research Group  
Steven E. Koonin, New York University  
Ronald K. Linde, California Institute of Technology  
Bjorn Lomborg, Kopenhagen Institute  
Michael E. Mann, Pennsylvania State University  
William D. Nordhaus, Yale University  
Edward A. Parson, UCLA  
Paul Sztorc, formerly Yale University  
Nicholas Stern, London School of Economics  
Daniel Swain, UCLA  
Jan Veizer, University of Ottawa  
Griffin M. and Julian S., UCLA  
Kelly Yang, UCLA

## SPECIAL CALLOUT

It may be a bit unusual, but our editor Mary Clare McEwing did such a superb job on helping us with the first edition of this book that she deserves a special callout. Thanks, Mary Clare — we could not have written this book without you!