Preface

Thermodynamics was a subject I thoroughly disliked when I was a student. I just could not understand the physics behind the rattling of exact, inexact, and partial differentials. And my interest in economics matched Thomas Carlyle's characterization of the field as the "dismal science," although at that time I did not appreciate the Malthusian basis of Carlyle's description.

These attitudes changed a lot as I grew older. Fascinated by many-body quantum mechanics, I got a first inkling of the practical usefulness of thermodynamics when John Bardeen of the University of Illinois at Champaign-Urbana gave me a problem for which I had to derive the time-dependent equations of motion for quasiparticles in inhomogeneous superconductors at finite temperatures. Minimization of free energy provided the important quasiparticle distribution function, and more. Later, my colleagues in the Physics Department of Universidad del Valle in Cali, Colombia, asked me to teach thermodynamics in their newly established master program. When I objected that this was the field I was least familiar with, they recommended Frederick Reif's *Fundamentals of Statistical and Thermal Physics* as the best book to improve my state of knowledge. They were right. Reif's combined statistical and phenomenological descriptions of interacting many-body systems pulled the veil from my eyes that had prevented me from seeing the beauty and power of thermodynamics. Finally, I understood entropy.

Then came the shock of the 1972 publication *The Limits to Growth*. I realized how naive I had been when I went to Colombia to join the efforts to industrialize this beautiful, tortured country by teaching physics to its gifted students. If industrialization, done the European and American way, were to spread to the developing countries, entropy production would create problems mankind had never faced in history. The next – oil price – shock, and the concomitant economic recession in 1973–1975, showed the vulnerability of industrial economies to reductions of energy conversion. These two shocks introduced thermodynamics and economics as the third theme, besides superconductor and semiconductor physics, of my teaching and research at the University of Würzburg since 1974.

I owe a lot to people who taught me more about economics and thermodynamics. First, there is the late Wilhelm Dreier, economist and theologian at the University of Würzburg. In joint interdisciplinary seminars on economic growth and its problems, I learned that in economic theory there is practically no room for energy as a factor of production beside capital, labor, and land. I found this hard to believe and asked Wilhelm for a good introduction to economics. He recommended Paul A. Samuelson's textbook *Economics*. This book educated me as much in economics as Reif's book did in thermodynamics. After the publication of my first article in an economics journal, the dean of theoretical physics in Würzburg, the late Helmut Steinwedel, established contact with Wolfgang Eichhorn from the Institute of Economic Theory and Operations Research at the Technical University of Karlsruhe. Working together with Wolfgang during the last 30 years has, hopefully, prevented me from falling into the interdisciplinary traps that await people who venture from their field into other disciplines. At one of the international conferences on economic theory of natural resources organized by Wolfgang, I met the late Willem (Pim) van Gool from the Energy Science Project in the Department of Inorganic Chemistry of the State University of Utrecht. Pim introduced me to energy, cost, and emission optimization in industrial systems, and to all that matters in exergy and enthalpy. Interaction with colleagues from the Working Group on Energy (AKE) and the econophysics community of the German Physical Society (DPG) has also fostered research in energy science and econophysics. During the first of a series of workshops entitled "Advances in Energy Studies," organized in 1998 by Sergio Ulgiati, then at the University of Siena, Charles A. Hall of SUNY at Syracuse, New York, Robert U. Ayres of INSEAD at Fontaienbleau, France, and I discovered our common interest in heterodox economics. Since then I have benefitted greatly from our cooperation and exchange of ideas. Personal encounters with the late Gerard K. O'Neill of Princeton University's Physics Department, and participation in three "Princeton Conferences on Space Manufacturing Facilities," inspired my hope that the collision with the limits to growth on Earth might be mitigated by a timely rediscovery of O'Neill's bold vision of *The High Frontier*.

Students are the heart of research. They work out the difficult details of an idea their advisor suggests and often carry on far beyond that. I was lucky that good students took the risk of doing interdisciplinary research, despite my advising them to be rather on the safe side with theses in semiconductor or superconductor physics. This book has benefitted in one way or another from my former students (in chronological order) Klaus Walter, Bruno Handwerker, Helmuth-M. Groscurth, Uwe Schüssler, Thomas Bruckner, Volker Napp, Alexander Kunkel, Hubert Schwab, Dietmar Lindenberger, Julian Henn, Jörg Schmid, and Robert Stresing. Dietmar Lindenberger, presently at the Institute of Energy Economics of the University of Cologne, is still an active partner in ongoing research. Arne Jacobs from my superconductivity group and Andreas Vetter helped with all sorts of IT problems.

During the last few years drafts of this book have served as a text for my course on thermodynamics and economics, and the feedback from the students who took the course has been very helpful. In that course and this book, I try to summarize the basic facts on energy and entropy, which are taught in Würzburg during the first five semesters of physics studies. This material is supplemented by information on fossil, nuclear, and renewable energy sources, the technological options of using them, and the possibilities of emission mitigation. Of course, it is only possible to discuss a subjective selection from the huge amount of research on these topics. The chapter on economic evolution is quite different from the preceding two chapters. It presents methods and results of research in energy and economic growth since 1980. These things have been published in peer-reviewed journals. The results are not in line with mainstream economic thinking. There are also people in the growing field of heterodox economics who agree with the results but dislike the mathematical methods used in their derivation. For them, the methods are too similar to those of neoclassical economics. The mathematics of orthodox economics, borrowed from classical physics, is attractive to a physicist. The idea has been to incorporate energy, entropy, and technological constraints into the orthodox mathematical machinery and see how the picture of economic evolution changes. The reader may judge for himself or herself whether the new picture, with the dominant role of energy conversion in economic growth and the threat from entropy production to future growth, is convincing or not. The time travel prologue with its qualitative description of natural, technical, and social evolution may facilitate the understanding of energy conversion as the driver of change without any mathematics. Ethical problems concerning economic development, and hope that proper action will be taken, are indicated in the epilogue. Some considerations are repeated in different parts of the book so that the chapters are self-contained and can be read independently of each other.

I am grateful to my colleagues in the Faculty of Physics and Astronomy of the University of Würzburg for not only tolerating my going partly astray from the path of monodisciplinary physics, but also for being helpful in many ways.

Last but not least, I thank my wife Rita for detecting inappropriate wording and lots of typographical errors, bearing with the physicists' priorities, and all encouragement.

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