This book is dedicated to Engineering Students everywhere. Especially mine.

Preface to the Electronic Edition

In the Spring of 2000, Brooks/Cole (the most recent publisher of record) declared *Energy Conversion* out of print and returned the copyright to the author. Because of the unavailability of the films used in the printing of the book, the author decided to develop an electronic edition for the world-wide-web by revising a word processor draft to conform to the published text, converting it to Adobe Acrobat pdf form, with minor modifications and corrections where needed.

This electronic textbook is offered in anticipation of the day when students will carry all of their texts and reference materials to class in a single electronic reader no larger than a book of a few hundred pages. Such readers are available now and notebook computers using the Acrobat reader could be used as such. It is in a spirit of conservation that the author hopes that students and other users will download chapters from the internet as they are needed and store them on their personal computers rather than printing them.

With the cooperation and assistance of Dr. Dale Schoenefeld and Ms. Janet Cairns of the University of Tulsa, it was decided to provide the ebook from the university server. The author very much appreciates their participation and that of the University in this effort. Dr. Andrew Dykes again contributed to the updated Chapter 10; and my scholar-wife, Ruth, proof-read the entire book and helped me to avoid a multitude of problems with the text. I am, of course very grateful for their contributions to this non-profit venture.

As I used the printed text as an instructor, before retiring, and as I worked on the electronic edition, I found a deeper appreciation of the quantity and quality of the efforts expended by the production editor of the printed version, Tad W. Bornhoft, and his associates. I came to admire and appreciate their work more and more. It was a job well-done. Thank you all very much.

I am grateful to the instructors and students who have used *Energy Conversion* in the past. It is for them and future scholars that I am attempting to make this work more readily available. I hope that they find it useful and that it makes a pleasant and meaningful contribution to engineering education.

Kenneth C. Weston
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Preface to the First Edition

A solid grounding in heat and power has long been a characteristic expected of mechanical engineers. This text deals with energy conversion topics that should be well understood by *all* mechanical engineers. It is intended for use in an introductory three-semester-hour course in energy conversion, to follow first courses in thermodynamics and fluid mechanics and, where possible, heat transfer. No attempt is made to treat electrical motors, generators, and other conventional electric power equipment dealt with in electrical engineering power courses. Rather, it focuses, in the first six chapters, on the three predominant thermal power systems: the steam power plant, the gas turbine, and the reciprocating engine. These are considered the mainstream energy converters in which all mechanical engineers should be well grounded. The remaining five chapters provide a variety of choices for an instructor to select to round out a three-hour junior or senior level course. While the latter chapters depend on fundamentals appearing in the first six chapters as much as possible, they are organized and written to be independent of each other, so that they may be used in almost any order, or may be completely ignored.

It is the author's experience that many students have difficulty with the concepts of thermodynamics and fail to grasp its importance and power. A course in energy conversion, which applies the concepts of thermodynamics and introduces and analyzes the prime energy conversion devices, can be an eye-opener to those students who need concrete applications and are stimulated by them. At the same time, a good course in energy conversion can motivate further study of thermodynamics and the other engineering sciences.

A number of textbooks are available for the study of energy conversion. Most of these books are best suited for advanced and graduate students because of an abundance of detail that may distract the undergraduate—fresh from first encounters with thermodynamics and fluid mechanics—from the fundamentals, from the major thrusts of system behavior and operation, and from engineering analysis. For this reason, the present text is an attempt at user-friendliness, which trades excessive technical detail for a fuller and easier development of mainline topics. Thus this text limits the amount of peripheral information presented and focuses on topics of current importance and those likely to play a significant role in the careers of the readers. It seeks to act as a convenient bridge between the engineering sciences and advanced courses and, at the same time, provide a useful terminal course for students pursuing other interests.

The approach taken is to provide a brief review of fundamentals from thermodynamics and fluid mechanics and to immediately focus on an in-depth study of a major energy conversion system—the steam power plant—together with more advanced fundamentals needed for its understanding and analysis. The premise is that a thorough understanding of a major energy conversion system establishes a point of reference by which the student may better appreciate and understand other systems. This is the major thrust of the first four chapters. The first chapter is a brief review and introduction to the text. Instructors may wish to assign the reading of Chapter 1 and a few problems for review at the first class meeting, and then answer questions and proceed to the important material of Chapter 2 in the second session.

Chapter 2 starts with the Rankine cycle and examines the important refinements of the cycle, one at a time, culminating in the study of a typical cycle of a large modern steam power plant. Sections of the chapter may be assigned at a pace consistent with the students' prior exposure to the Rankine cycle. The author usually assigns one or more problems at each class and spends one class each on the basic cycle, reheat, efficiencies and pressure losses, regeneration and feedwater heaters, combined mass conservation and First Law analysis with heaters, and two classes on the study of the power plant flowsheet. At this point the student should have the capability to interpret and analyze the flowsheet of any steam power plant presented to him or her. This may be an appropriate time for a first examination to assure that the attention of the student has focused on thermodynamic cycle and system analysis fundamentals before considering the basics of Rankine cycle implementation.

With a good grasp of the cycles of steam power plants in hand, it is appropriate for the student to study some of the fundamentals of fuels and combustion in order to proceed further in understanding steam plant design and operation and to prepare him or her for later chapters. Thus the student should be easily motivated to the study of fuels and combustion in Chapter 3. To the extent that this and the preceding chapter are review for the student, the pace of coverage may be adjusted by the instructor in reading and problem assignments and class discussions.

Chapter 4 completes the study of conventional steam power generation by following and analyzing the major flows in a steam plant: water, fuel, and gases, placing emphasis on the hardware and systems involved in these flows. A brief introduction to the fundamentals of engineering economy is included in this chapter, so that financial aspects of power plant operation may be considered. The latter material is not intended to replace a course in engineering economy. Instead, it provides basic information that may appear too late in some curricula for use in a junior-level energy conversion course. Chapter 4 concludes with a back-of-the-envelope type analysis of plant characteristics, which provides the student with an overview of the magnitudes of parameters associated with large steam plant operation and with an opportunity to reflect on the roles of thermodynamics, economics, and analysis in the plant design.

The succeeding chapters provide opportunities to show the universality of many of the fundamentals and methods presented in the first four. The fifth chapter treats the important and exciting topics of gas turbines and jet propulsion. The characteristics of stationary gas turbines are studied and contrasted. The jet engine is studied as a form of gas turbine with special design and performance characteristics. Care is taken to provide the student with a conceptual understanding of the basic machine before delving into detailed analysis and alternate configurations. Advanced topics such as combined cycles, cogeneration, steam injection, polytropic efficiencies, and turbofan engines are deferred to Chapter 9, for those instructors who prefer not to treat these topics in an introductory energy conversion course.

As in other chapters, the instructor is largely in control of the level of the presentation by the choice and the pace of the assignments that he or she makes. One or several text sections may be assigned per class meeting, along with problems of appropriate number and difficulty for the students. At the end of Chapter 5, the instructor may wish to assign the development of a computer program or a spreadsheet for gas turbine analysis, or the use of an existing program or spreadsheet for optimization of a configuration for a given application, or for a preliminary design study of a gas turbine or steam plant. Although combined gas turbine and steam cycles are not considered until Chapter 9, some instructors may wish to deal with them at this point, and perhaps assign a design problem.

Chapter 6 considers the phenomena and characteristics of the reciprocating engine and the engineering parameters describing its performance. The chapter develops and compares models of both Otto and Diesel cycles and explores some of the fundamental problems and aspects of their implementation in working engines. Chapter 7 complements Chapter 6 by providing a brief look at the Wankel rotary engine. While not a major player in energy conversion at this time, the rotary engine offers a unique opportunity for students to analyze and understand an entirely different, successful, and intriguing implementation of the Otto cycle. For those instructors wishing to substitute other materials, Chapter 7 may be omitted without concern for student comprehension of the remainder of the book.

While refrigeration and air conditioning are not power generation technologies, they clearly involve energy conversion in important ways and represent an important mechanical engineering discipline. Chapter 8 briefly considers the fundamentals and hardware of this field briefly, giving a framework within which HVAC engineering may be understood and upon which engineering analyses may be built. The important topic of the analysis of moist air is introduced by treating moist air as a binary mixture of ideal gases and carried to the point where the student is introduced to HVAC system design using the psychrometric chart.

Chapter 9 considers some of the important technological problems of the day and a selected collection of advanced energy conversion techniques that mechanical engineers use to deal with them. The treatments of most of these technologies are largely independent of each other, so that instructors may elect to use either the entire chapter or only those advanced topics that they consider most appropriate for their course. A notable exception is that the presentation on turbofans considers using either isentropic or polytropic efficiencies. It is recommended to cover the preceding section on polytropic efficiency before proceeding to turbofans. It is hoped that the study of this chapter will motivate students to investigate the selected topics in greater detail, aided by the bibliography. Instructors may wish at this point to assign more in-depth study using the library on one of these topics or on other advanced systems.

Certainly, nuclear power is controversial. While the development of new nuclear fission plants in the United States is currently dormant, the subject remains important and is likely to become more important to mechanical engineers in the future. Some texts devote a great deal of space to nuclear power while others do not choose to treat it at all. The decision here was to take the middle ground, to provide a survey that allows mechanical engineers to place the subject in perspective with respect to other major energy conversion technologies. Chapter 10 thus focuses on relevant aspects of nuclear fission power without going into nuclear reactor physics and design in detail. The chapter may be studied at any time after the first four chapters on steam power, or may be omitted completely if the instructor desires.

The final chapter offers vistas on a number of promising technologies, some of which avoid the heat engine approach that dominates today's modern power and propulsion systems. An introduction to electrical energy storage-battery technology provides a lead-in to fuel-cell energy conversion, now under intensive development as a flexible solution to a diversity of electrical power generation problems. Magnetohydrodynamics (MHD) is considered as a means of producing electricity directly from a hot fluid without the use of a turbine. The inspiration of the sun as a massive and eternal energy source continues to drive interest in solar energy, spurred by the success of small-scale photovoltaic conversion in watches and calculators, and of remote power applications. The chapter closes with a brief consideration of the use of hydrogen as a secondary energy source and the transition to a steady-state energy system.

A course in energy conversion may serve as a terminal course in the thermal-fluids-energy stem for those students pursuing other disciplinary interests. These students emerge with an appreciation of the purposes and methods of thermodynamics, of engineering hardware, and of important segments of industry. For others, the course may serve as a motivating lead-in to electives such as advanced thermodynamics, advanced fluids and heat transfer, refrigeration and air conditioning, solar energy, turbomachinery, gas turbines, and propulsion. At the University of Tulsa the course is offered to sixth semester students, allowing elective studies in the seventh and eighth semesters.

The goal of this book is to provide a lucid learning tool for good students who may feel insecure in their understanding of the engineering sciences and their uses. An effort is made to tie theory, concepts, and techniques to earlier courses, which may not have been mastered. A special effort is made also to help the student become familiar with and appreciate the important hardware associated with energy conversion, through the presentation of numerous photographs and diagrams. The author hopes that this study of energy conversion will not only prepare the student for work in this field but will also provide motivation for further study of the engineering sciences because their usefulness in design and analysis is better appreciated.

Numerous examples are provided in the text in connection with the more important topics. Photographs and schematic diagrams of modern equipment are included to aid the student in hardware visualization. Students should be encouraged to study these carefully as the useful learning tools that they are. As a further guide and aid to the student, terms which should be part of his or her vocabulary are italicized. Many acronyms and abbreviations are used in energy conversion as in other fields of endeavor. There is no point in delaying the inevitable. They are used sparingly but where appropriate in the text and are identified in their first occurrence and in the list of symbols.

We are in the midst of a protracted transition from one system of engineering units, *the English system,* to an international system, the Systeme International d'Unites, usually called *SI.* It is essential that this and other texts provide experience in using both; therefore, an effort has been made to provide discussions and problems expressed in both the SI and English systems.

The importance of units, not only as a tool of communication, but as an analytic tool warrants repeated emphasis. Using units for dimensional analysis may often be the difference between obtaining a correct problem solution and falling into quantitative error. To emphasize the importance of units, equations in the text appear with the units of the dependent variable in both English and SI forms in brackets, as for example in the units of specific energy: [Btu/lb_m | kJ/kg]. When an expression is dimensionless that fact is indicated by [dl] following the equation.

The personal computer has become a valuable tool for practicing engineers and should be used by engineering students at every appropriate opportunity. The author has found spreadsheets to be particularly useful in a variety of activities including energy conversion. Spreadsheets are provided for the example problems presented in spreadsheet format in the text. This allows students to examine these calculations in as much detail as they wish, to conveniently repeat the calculations for alternate inputs, and to substitute alternate calculation details. Thus instructors may conveniently assign "what if" studies in these cases. A spreadsheet of data extracted from the JANAF tables is included to allow easy flame temperature and heat transfer calculations in connection with Chapter 3. While the spreadsheets were developed using Quattro Pro, the examples are provided in the WK3 format, so that they may be used with any spreadsheet that is compatible with this popular Lotus 1-2-3 format.

Those unfamiliar with spreadsheets will find that a few hours with a modern spreadsheet and a good tutorial will enable its use in powerful ways. One of the characteristics of spreadsheets is that the new user can usually start solving problems at the first sitting. After using the tutorial, the new user should pick a modest problem of current interest to solve, or try a few problems that were previously completed by hand. It is wise for new users to select a spreadsheet that is widely used in their university or company or by their friends, so that it will be easy to exchange information with and learn from others.

During the years of preparation of this book, many friends, colleagues, reviewers, and students have made constructive suggestions and offered ideas and encouragement. They are too numerous to thank individually here. It is, nevertheless, appropriate to express my appreciation to them and to acknowledge their invaluable contributions. It is particularly fitting, however, to recognize the special contributions of friend and colleague, Dr. Andrew A. Dykes, for both his insightful critique of the first draft and his substantive and continuing contributions to Chapter 10. Some of his expertise is written into the pages of that chapter; any deficiencies there are mine. I am greatly indebted also to industry for providing many of the photographs and illustrations that the reader will find in these pages. Sources are identified with the figures. Finally, I must acknowledge the patience and support of my family and the administration, faculty, and staff of the University of Tulsa, who helped ease the pain and maximize the joys associated with the preparation of this work.