

Fuel Cells, Engines and Hydrogen

An Exergy Approach

Frederick J. Barclay

C.Eng., C.Phys.,

F.I.Mech.E., F.I.E.E., F.Inst.P.



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This book is printed on acid-free paper responsibly manufactured from sustainable forestry in which at least two trees are planted for each one used for paper production.

This book is dedicated to my wife, without whom it could not have been written. The dedication poem below is written in a mixture of Buchan Claik (Buchan dialect) and Lallans (Lowland Scots), as befits a marriage between a husband from Edinburgh, but of Glaswegian upbringing, and a wife from Aberdeen. In Buchan Claik loons (m) and quines (f) are marriageable young people.

My Bucksburn Quine

O Mary, it's lang syne we click'd,
While touching over teacups,
I tak't ye fae a jilted loon,
Sair sick doon in his stommick.

My Bucksburn quine had black dark hair,
That spark'd a'twixt the bed sheets,
Glintin' the way tae lovers rites,
That spritely gint the hert leap.

The potter's clay from high she thumps,
Upon the caring plaster,
Wi' micht an main, tae get it richt,
Tae form, and fire, and gloster.

My Buchan quine, ma ain guidwife,
In the game o'life, a winner,
O'er wrongs and rights, and deil made plights,
That yowt the heid's wee spinner.
A doughty fechter in the fight,
Wi' posture, and good balance,
An' shak', will she, the hand o' God,
When life's brief flash is darkened.

Our bairns, and bairns's bairns are fair,
A trace we'll leave behind us,
Meantime the bond o'blood is there,
That joins and keeps and twines us.

A fortun'd, fair starred man am I,
Health's, wealth beyond conception,
And love thy neighbour as thy self,
Precludes the deil's pre-emption.

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Foreword

At first glance, the detailed study of how equilibrium thermodynamics may be used to analyse fuel cells seems far removed from the mainstream of fuel cell development. Fuel cell developers are necessarily caught up in a trade where increased irreversibilities are embraced in return for reductions in capital cost and comparisons are made with heat engines from the flawed but familiar mindset of energy and heating values. However, such perspectives, comfortably close though they are to current thinking, ignore not only the full potential of fuel cells to impact the exchange of useful work but also the benefit to be gained from a fresh approach to the engineering of fuel cells from a fundamental perspective.

The study of seemingly abstract aspects of quantum mechanics and solid state physics led paradoxically not only to semiconductor devices themselves but also to fresh insights into how pragmatism could be used to engineer these devices into even more useful forms that could be connected in a highly integrated fashion and dramatically reduced in size. Fresh study of the detailed thermodynamics of fuel cells is at the very least a valuable intellectual exercise for any practitioner in a fuel-cell-related discipline. With a little historical reflection, few could ignore that it might lead to further insights that could directly benefit the pragmatic development of commercially saleable fuel cells.

In Mr Barclay's latest work we see not only a more comprehensive equilibrium thermodynamics analysis than in his previous works but also a much awaited bridge to the practical world of fuel cell development along a path where irreversibilities are recognised for what they are – undesirable concessions in which potentially useful work is given up. The crux of Mr Barclay's book is his revision of the nature of isothermal oxidation, the process which generates the potential difference of

a fuel cell, at zero-current equilibrium, or when generating current and power. Mr Barclay places the maximum possible work of a fuel cell at a very high new level, and dismisses the calorific value of the fuel as a basis of comparison for fuel cells. The revision is far reaching, and will undoubtedly be accepted only slowly and begrudgingly by a field that is quick to open up fresh searches for paradigm shifts but is slow to recognise brilliant fresh thinking in its midst.

The book is doubly ambitious in attempting to point the way to the 'hydrogen mine' or source of low-cost hydrogen. Moreover it highlights the difference between compressible gaseous fuels and relatively incompressible liquid fuels for fuel cells.

Mulling over of the book will be an extended task for fuel cell and hydrogen economy protagonists, and we must await the results. Perhaps a piece of common ground is to look forward to economical coal utilisation via distillation of gaseous fuel for integrated fuel cells and gas turbine engines. Or then again perhaps, armed with fresh thermodynamic insight, there are better ideas to be had on how to use nuclear power to extend the work obtainable from gas and oil.

Gerry Agnew
Vice-President, Rolls-Royce Fuel Cells
Derby, UK

Introduction, and Commentary on Matters Affecting all Chapters

A child's amang ye, takkin notes!
And, faith, he'll prent it.

Robert Burns

This introduction is rather long, since it includes that matter which is common to all of the following chapters in the book, some of which are new and unique to the book. A first-time lead is provided into the revolutionary new technology of isothermal oxidation, detailed in the thermodynamic appendix (Appendix A). The reaction in a fuel cell is isothermal, charge exchange, oxidation. Combustion does not occur, and its theory does not relate to fuel cells, nor does its main parameter the calorific value or combustion enthalpy.

The author's position is roughly that implied in Burns' remark above. The fuel cell community is young and interdisciplinary. Retired fuel cell technologists are still rarities, so that distillations of long-term extensive experience are hard to come by. Moreover, such experience will not have been against the new background fully developed in this book for the first time. The new fuel cell isothermal oxidation theory is remarked upon in the foreword, and was partly introduced by Barclay