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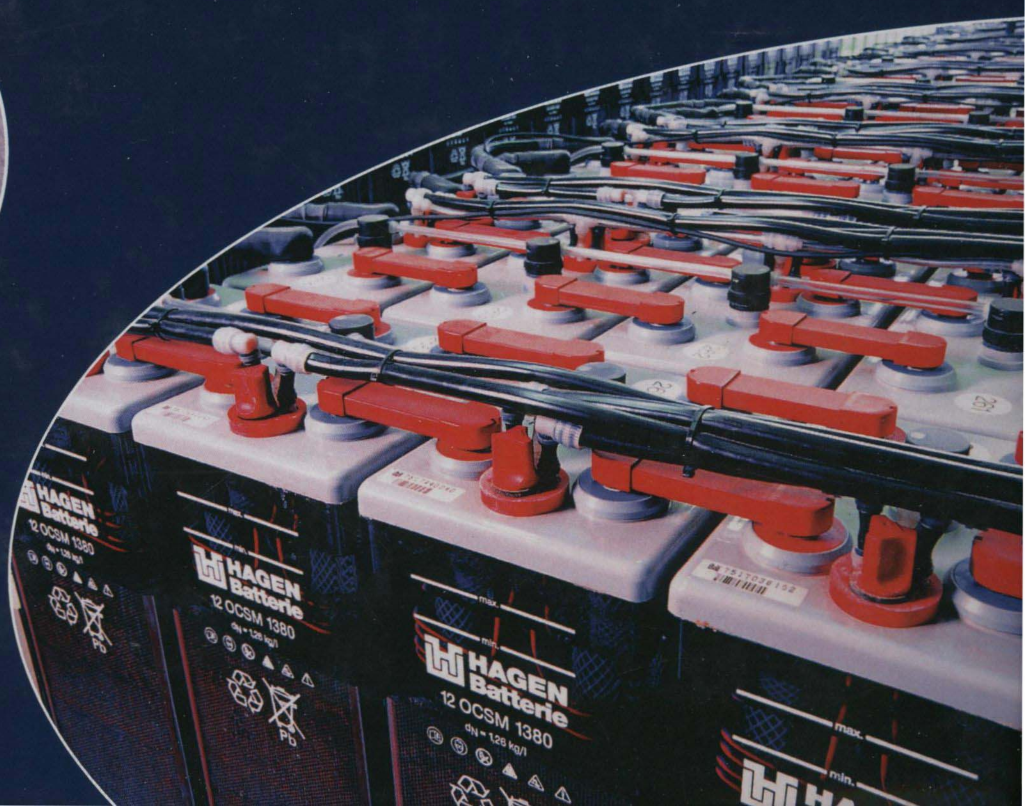
Electrochemical Energy Storage for Renewable Sources and Grid Balancing



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Elsevier
Radarweg 29, PO Box 211, 1000 AE Amsterdam, Netherlands
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK
225 Wyman Street, Waltham, MA 02451, USA

ISBN: 978-0-444-62616-5

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

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Foreword by Dr. Derek Pooley†

Electrochemical Energy Storage is already big business, but it will grow dramatically if the technology can be sufficiently improved—or its costs can be reduced sufficiently—or novel ways can be found of using it. The driving force is the inexorable rise of electricity in powering modern life.

Electricity is an ideal bulk-energy vector in almost all respects, already crucial for twenty-first century life. It provides lighting, heating, cooling, ventilation, mechanical power and is essential for all the modern tools of information, communications, and entertainment. It can be moved easily over long distances with relatively little loss. It is always perfectly clean at the point of use. The end-use equipment is usually compact, quiet, and cheap to manufacture. Freezers and cookers, washing machines and dish washers, TVs and computers, machine tools and hedge-trimmers, trains and cars; the list of its uses is endless. If earlier ages of mankind were best characterized by the materials we used for our tools, the stone age, bronze age, iron age etc., then our age is the power-tool age, and our tools are powered mostly by electricity.

Moreover, electricity will have to extend its reach much further and become even more important if our society is to save planet Earth from the climate-changing consequences of burning too many of our fossil energy resources too quickly. This is because almost all the 'alternative' energy supply technologies, that is, alternative to fossil fuels, which may allow us to 'decarbonize' our energy supply system and mitigate artificial global warming, are electricity-producing. Nuclear power, wind, solar, wave, tidal and other ocean energies, coal combustion with CO_2 capture and sequestration are all basically electricity producers. There can be no doubt that electricity must become even more important in the future than it is now.

But electricity has a major Achilles' heel, the difficulty of storing it, which makes coping with any variability of demand and supply a major task in any electricity-driven economy. Demand has always varied with the patterns of daily living. Now supply is becoming inherently variable too, because of the natural variability of wind, solar etc., and at the same time becoming inherently less flexible, as nuclear power generation and complex fossil cycles such as clean coal with carbon sequestration replace simple fossil generation. Currently, the electricity grids of most advanced countries deal with variability via the so-called dispatchable generators, which can easily be turned up or down, or on and off. They are mostly fossil-fuelled, so that dealing with variability effectively 'locks' fossil-fuelled generators into our electricity infrastructure. More use of electricity storage technologies would allow us to reduce net variability, make better use of new generator technologies, lessen fossil fuel dependence, and bring enormous benefits.

The simplest (and already-widely used) way to store bulk electricity is with hydro power, especially pumped hydro, but gravity is a very weak force of nature and storing bulk electricity this way requires large volumes of water to be pumped through, or held at, large differences in height. This can be achieved only in mountainous terrain but even countries with mountains are often severely limited in the number of good hydro sites they can use.

In contrast, the chemical-bond forces involved in electrochemistry are inherently much more powerful than gravity and it seems obvious that electrochemical energy storage should be used as well as hydro power to store bulk electricity, especially in countries without mountains. Electrochemical storage can also be local, perhaps linked to solar photovoltaic arrays installed on the roofs of individual houses. Moreover electrochemical energy storage, via batteries or hydrogen production, might also allow decarbonising much of our transport energy use as well and although road transport's contribution to CO_2 emissions is only half that of electricity generation, it is still very significant.

Unfortunately, today's batteries have many and varied imperfections of their own. Stored energy to weight and/or cost ratios are frequently too small. Very fast charging is usually difficult. Deliverable power to stored-energy ratios

† **Dr Derek Pooley, CBE FInstP,** is now retired after some 15 years working as an independent consultant on nuclear and other energy technologies, which followed some 35 years working full-time in energy and materials technologies. His appointments included chief executive of the UK Atomic Energy Authority, chief scientist at the UK Department of Energy, chairman of (*Radioactive*) Waste Management Technology Ltd, chairman of the European Union Nuclear Scientific and Technical Committee, president of the British Nuclear Energy Society (now the UK Nuclear Institute), and member of the European Union's Advisory Group on Energy.

are not sufficient for many applications. The limit on the number of charge/discharge cycles, after which the battery performance is too seriously degraded for further use, is often too small for daily usage cycles. Batteries are wonderful for flashlights and tablet computers but not yet a panacea for bulk electricity storage.

Other forms of electrochemical energy storage, such as the manufacture of hydrogen or methane, also have their own problems, especially for small-scale or mobile use. The storage of hydrogen is basically difficult. Its efficient use requires fuel cells that are still much too expensive for widespread use, not least because very-expensive platinum is often needed for the catalysts essential to their operation.

Although the title of Patrick Moseley and Jürgen Garche's book is electrochemical energy storage, it does recognize possible competition: pumped hydro, flywheels, thermo-electric, magnetic and compressed gas energy storage, etc. As Chapter 7 says, the number of possible storage technology concepts is nearly infinite. The book also covers potential markets, in particular the increased need for storage coming from the massive investment in renewable energy sources.

Electrochemical energy storage is without doubt a potential gold mine, but only for those technologists and entrepreneurs who can think or invent their way round the problems that currently limit its widespread use for bulk energy storage. Moseley and Garche's book is an information mine for those technologists and entrepreneurs—and for potential users—of where the technologies stand and how they currently fit the applications foreseen for them.

In fact, Moseley and Garche have written only some of the book themselves. In addition they have persuaded a large number of experts to write about their own fields, which has the advantage of including what real experts have to say but inevitably results in a tremendous variety of styles and approaches. Although written in English, the expertise and experience deployed are almost exclusively from Germany; not surprising given the German determination to decarbonize its economy and the constraints imposed—and self-imposed—on their energy system.

Dr. Derek Pooley
08/05/2014

Preface

Patterns of electricity generation and use are changing markedly during the early part of the twenty-first century. Driven by concerns over global warming, governments and corporations around the world are beginning to shift away from generating plant that depends on fossil fuels towards a 'sustainable' future based on renewable (sun, wind, hydro-power, etc.), and in some cases nuclear, energy. The changing nature of the primary generating equipment brings with it a need to cope with fluctuations in supply that can only be managed with the aid of some form of energy storage. There are a wide variety of applications in view ranging from large-scale supply-side plant that can help to cope with frequency control, load leveling, and arbitrage, to small demand-side systems that assist the use of solar energy that is harvested in the user's own home. Simultaneously there are many ways that energy can be stored, including engineering options that make use of physical properties (compressed air, flywheels, superconducting magnetic energy storage, etc.) and electrochemical storage.

This book is a multi-author work and chapter subjects have been selected to cover the full range of requirements and options for energy storage in future schemes for generating and using electrical energy in an environmentally friendly manner. The principal focus is on electrochemical methods of energy storage including batteries, fuel cells, and supercapacitors although some consideration is also briefly given to the non-electrochemical methods mentioned above. Many examples of schemes in action, or planned, are taken from Germany, which has probably the most advanced plans of all the major industrial nations for the introduction of renewable energies into its inventory of electricity generating plant. Individual chapters are intended to be stand-alone and, since they do relate to one central theme, a small amount of subject overlap has been unavoidable. In particular, the role of storage as the key to enable the introduction of renewable sources of energy to be effective is stressed.

The exploitation of hydrogen as an energy storage vector is dealt with in three chapters that cover the following three subtopics: hydrogen generation, hydrogen storage, and hydrogen conversion. The hydrogen system is considered from both the R&D and the industrial viewpoints and, again, there is a small amount of overlap between chapters at the boundaries of the subtopics.

Patrick T. Moseley and Jürgen Garche

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