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The Bourner lecture
Power sources and the new energy economy

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Abstract

This paper focuses on the critical role of power sources in the future energy economy. It highlights the disruptive nature of the new energy technologies that will come into play, addressing the problems of greenhouse emissions and reduced availability of fossil fuel reserves. The importance of power sources such as fuel cells and batteries is discussed and their inter-relationship with the hydrogen economy explored. Overall it is clear that improved methods of energy storage are of critical importance and these must be optimised both in terms of cost and energy density. There are important challenges to be addressed; however, very positive outcomes can be anticipated.

Keywords: Future energy economy; Fossil fuels; Renewable energy sources; Electrochemical energy sources

1. The new energy economy

There are a number of key drivers to change our current fossil fuel dominated energy economy. Firstly, we are rapidly approaching the position where cheap oil and gas are no longer readily available. It is predicted [1], that the world crude oil supply will peak in 2015 and at this point cheap oil will cease to exist as demand will outstrip supply. It is suggested that this shortfall could be satisfied with unconventional oil produced from sources such as tar sands or oil shales; however, it is inconceivable that such unconventional oils can be economically produced at current oil price levels.

Similarly, natural gas is becoming less available with, for example, North Sea stocks now decreasing significantly and the UK starting to import significant amounts of natural gas from Siberia. There are still quite significant reserves of coal, most notably in China and the USA, and there are strong pressures to utilise this form of fossil energy. Secondly, there is the issue of security of energy supply. Partly, as a consequence of the demise of certain fossil fuel resources, but more especially due to perceived political problems, many of the developed nations wish to ensure security of energy supply and so are implementing major changes in the energy economy. Thirdly, and most importantly, concerns about greenhouse gas emissions especially from carbon dioxide (CO_2) strongly mitigate against utilisation of fossil fuel sources, unless there are significant improvements in conversion efficiency.

Further drivers for the restructuring of our energy economy, relate to environmental concerns in association with planning. There is a growing reluctance to accept large-scale generation systems and especially the associated high voltage transmission lines. Public objections at planning inquiries, mean that centralised large-scale electricity generation now faces considerable difficulties in establishing new facilities in terms of expense and even a lack of certainty that planning permissions may even be forthcoming. Obviously, these difficulties are magnified significantly with nuclear power generation due to the long-term uncertainties of nuclear waste storage and its acceptability.

2. Static generation

The result of these driving influences is that there are now intensive world-wide efforts towards implementing a new energy economy. This energy economy will be largely based on renewable generation from wind, wave, hydroelectric, tidal, biomass and photovoltaic systems. This generation will be necessarily distributed in nature. The electricity supply network will move from a central system distributing electricity out towards the periphery to a distributed system generating electricity ideally close to the point of use, but to quite a significant degree remote from both centre and point of use.

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A key character of many of these new renewable energy sources is intermittence of supply. Photovoltaic devices can only generate when the sun shines, which necessitates at least a diurnal cycle of supply. Wind and wave are wholly dependent upon climatic conditions with very large variations in output over very short periods of time. Tidal is more reliable, but again has a twice-diurnal cycle. In every case this means that in the absence of storage, these systems need to be designed grossly-over capacity with a peak capacity perhaps 5–10 times that which might be required as an average output.

With this background, energy storage becomes hugely important. Balancing of load by storing energy from high power generation periods to be later utilised as back up in low generation periods will be of considerable economic importance.

Similar considerations apply to other new clean technologies, such as power generation from fuel cells, and such technology is again likely to result in a highly distributed network. This is driven both in terms of security for local supply, and by the fact that there is no great advantage in having very large generation systems for fuel cell technology due to the excellent scalability of this technology. With fuel cell technology, it is quite likely that power will be locally generated on typically 1–5 MW scale [2] with each locality or conurbation having its own independent generation capacity, albeit with interlocality grid connection. Such technology will be much less dependent upon energy storage than renewables as output can be controlled to match demand, although fuel supply is of course an important constraint.

3. Transport applications

The consideration so far has been related to static systems for energy utilisation; however, mobile systems are extremely important. Transport is responsible for 30% of fossil fuel utilisation [3]. It is extremely difficult to utilise renewable energy sources for transport directly, with the exception of some older technologies such as sail power. Thus in a new energy economy that is largely based on renewable resources it is essential to store the renewable energy in some form and then distribute that energy before it can be utilised in a vehicle.

The most obvious solution for this is hydrogen and the hydrogen economy certainly looks a very promising way forward for transport in particular. The likelihood is that the hydrogen will be produced electrochemically from renewable resources, distributed perhaps in compressed form, and utilised on-board with a fuel cell. Unfortunately, whilst this is clearly a pollution-free energy vector there are a number of complications that render its clean credentials somewhat suspect, at least in the short-term. First of all the cheapest and most direct early source for hydrogen production seems certain to be the reforming of hydrocarbons with significant CO_2 emissions. Barring sequestration, such emissions would be no less and quite possibly more than could be achieved if the fossil fuel was used directly, especially in a fuel cell. Secondly, the compression and storage of hydrogen is fairly energy-intensive with losses of perhaps 10% in compressing hydrogen or 30% in liquefying hydrogen [4]. Considerable research has been embarked on to find alternative solid state means of storing hydrogen, unfortunately the storage density of hydrogen is still very low, typically in the order of a few percent mass density of hydrogen. If hydrogen is generated renewably there are significant losses in hydrogen production. For example, the efficiency of generation of hydrogen by electrolysis is at the very most 80% energy-efficient using the best currently available processes. Alternative vectors such as ammonia, ethanol or methanol must seriously be looked at, especially in view of their much superior volumetric/mass density when compared to hydrogen. Although hydrogen is a very clean fuel in itself, its physical properties do not render it particularly amenable to utilisation. It is extremely likely that hydrogen or a related energy vector will be developed for utilisation in the transport industry in the foreseeable future, although this is perhaps not that likely to achieve dominant implementation before 2050. All things being equal, one would never wish to transform one energy vector into another if one could utilise that energy vector directly in the first place; however, it seems unlikely that electricity can be directly utilised in transport applications and indeed there are considerable advantages in load levelling—thus some sort of conversion of electrical energy will be required to produce a vector that can be transported in a different manner to electricity, as is gasoline for example.

4. Energy storage

There are probably two dominant types of energy storage systems required for the new energy economy, one related to static load levelling of renewables and the other to transport. For both, cost and reliability are extremely important, energy and power density are also important although to differing degrees. The energy densities available from different chemical fuels and energy storage devices are presented in Fig. 1.

Note that 10% by mass for hydrogen storage density has been assumed, a figure that should be viewed as a target rather than a currently available figure.

Although fuels do require an additional conversion device such as a fuel cell or internal combustion engine to be comparable as a power source to a battery, it is still very clear that batteries are more than an order of magnitude less in energy density. It is thus not surprising that electric vehicle development has now largely moved from battery-powered vehicles to hybrids with internal combustion or even fuel cell drives. Here it is power density rather than energy density that is all-important. Of particular interest to these applications are nickel/metal hydride, lithium [5] and high