John Mills
Institute for Prosperity

UK ECONOMY

Decarbonising the Economy: The Role of Batteries and Fuel Cells

Professor Stephen Pollock

“This paper is a vital intervention into the debate around energy storage in the UK at a time when these new technologies will determine the future success of our economy.”

John Mills

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'Decarbonising the Economy: The Role of Batteries'

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Stephen Pollock has also written on a variety of topics, including medicine, agronomy and paleoanthropology. He is a member of the House of Lords, with the title of Viscount Hanworth, and sits on the Labour benches.

He has served until recently on the Energy and Environment Sub-Committee of the European Union Committee of the House of Lords and he participates in ad hoc committees on legal affairs. He is currently a member of the committee that scrutinises secondary legislation.

JOHN MILLS INSTITUTE FOR PROSPERITY

The John Mills Institute for Prosperity (JMI) is a cross-party research initiative that seeks to provide policymakers of today and tomorrow with new, innovative, and fresh ideas to increase levels of prosperity and growth.

By working with policy stakeholders, legislators, business and industry leaders, trade union representatives, economists, commentators, regional leaders and the public, the Institute for Prosperity aims to bring policymakers together to affect change and find new solutions to Britain's economic problems.

The Institute believes that Britain must raise its sights and reject 1% economic growth per year, which has become the new norm. By investing in economic growth and getting our economy to grow at over 3% per year, we will increase levels of prosperity across the whole nation and ensure no one is left behind.

We are supported by an expert Advisory Board. With MPs and Lords from across the political spectrum, former ministers, academics, and business leaders, the Institute for Prosperity is made up of a diverse and broad range of opinions, ideas and solutions, and we fundamentally believe we are stronger for it.

FOREWORD

BY JOHN MILLS

As the founder of the Institute for Prosperity, I am delighted to write the foreword for this important new pamphlet on the role of batteries in decarbonising our economy.

The Institute for Prosperity was established on a cross-party basis to trigger discussion around reviving UK manufacturing and to provide policymakers with innovative new ideas to increase prosperity and economic growth. Improvements in battery technology are key to ensuring Britain's continued manufacturing success, and having a forum where we can discuss how this fledgling industry will be structured is of the utmost importance.

This paper by Professor Stephen Pollock is an important intervention into the debate around batteries and the ongoing energy transition in the UK. Demand for battery storage has seen exponential growth in recent years, due in no small part to the need to decarbonise our economy. That is why it is incredibly important that we have this depth of expertise that ensures the UK can stay competitive and not fall behind the rest of the world.

I was particularly struck by the commentary around the future supply of electricity for UK industrial processes. Even energy intensive processes, like the manufacture of steel and cement, will need to be powered by electricity, and battery storage will be vital in ensuring we can continue manufacturing and decarbonising simultaneously.

My hope is that this detailed and well-researched contribution to the debate around our manufacturing and energy ecosystem will not only lead to further debate on the topic, but also, more importantly, will prompt more people within and outside Westminster to conduct further research into battery technology and the policies we need in the UK to compete internationally.

I do hope that the Government will consider this contribution carefully and find ways to integrate its conclusions into the policy-making process. At a time when energy prices are in the headlines, it is not only important to find short term solutions to these important issues, it is also important that we look forward to the new technologies that will position our economy for success in the next three decades.

John Mills
Founder of the Institute for Prosperity's
Founder and Chairman of JML

ABOUT JOHN MILLS

John Mills is the founder of the Institute for Prosperity. He is also the founder, Chairman and majority shareholder of consumer goods company JML. He has been a Labour Party supporter, donor, and activist for over 50 years. As a noted economist and author, he has published over 12 books over the last 40 years on a range of political and economic issues.

INTRODUCTION

The Science and Technology Select Committee of the House of Lords is a long-standing committee that has to its credit many well-informed reports. Its role is to consider developments in science and technology and to assess how they might impact the Government's decision-making. It is liable to criticise any shortfalls in policies that disregard available scientific knowledge or opinions.

The recently published report of the committee concerns the role that electrical batteries and hydrogen fuel cells can play in decarbonising transport in the UK. The critical stance of the report is evidenced by its title: Battery strategy goes flat: Net-zero target at risk.

The committee chose to pursue this topic after considering a range of options that were suggested by a preliminary seminar devoted to the problems arising from global warming and the means of addressing them. The choice was influenced by an awareness of what other parliamentary committees were focussing on.

Thus, given that the Science and Technology Committee of the Commons has chosen to investigate the role of hydrogen in achieving net zero, it was felt necessary to avoid this topic. This may have had the consequence of limiting the remit of the Lords' enquiry.

Thus, whereas hydrogen fuel cells were to have been a topic of equal importance to that of batteries, they were somewhat neglected. The committee also neglected to make an assessment of the demands for electrical energy that might arise from the electrification of transport and from the pursuit of other policies aimed at decarbonisation. This oversight is shared with the national government.

The Present and Future Consumption of Energy in the UK

The potential contribution of batteries and fuel cell technologies in the UK to the reduction of emissions should be considered within the context of the nation's total energy consumption and its total emissions.

	Industry	Domestic	Transport	Services	Total
Coal & other fuels	1.2	0.5	0.0	0.0	1.7
Gas	8.8	26.6	-	8.2	43.6
Oil	2.3	2.6	54.4	3.8	63.1
Electricity	7.9	8.9	0.5	8.1	25.4
Bioenergy & heat	2.1	2.7	1.7	1.6	8.2
Total	22.3	41.3	56.7	21.7	142.0

Energy Consumption in 2019 by fuel and by sector in millions of tonnes of oil equivalent. (ONS)

The transport sector of the UK is responsible for 40% of the total energy consumption. The energy consumed by transport can be attributed to five types of transport, which are road, air, rail, shipping, and aviation.

Road transport accounted for 74% of total transport energy consumption in the UK in 2019. Of the total energy consumed by road transport, an estimated 63% related to passenger transport and 37% to freight transport. Air transport accounted for 23% of total transport energy consumption. Rail transport accounted for 1.9% of total transport energy consumption. Water transport accounted for only 1.4% of total transport energy consumption.

These figures indicate that road transport is a significant consumer of energy. This energy is derived almost entirely from fossil fuels. The inference is that, by staunching the emissions from transport, the UK could reduce its total emissions substantially.

The energy consumed in transport is mostly imported. Its replacement by non-carbon fuels would require the energy to be generated domestically and to be conveyed in the form of electricity for charging batteries, or in the form of hydrogen or ammonia to be used in fuel cells, or in the form of some other synthetic fuel.

It is inevitable that electricity will become the prime mover of a decarbonised economy. At present, the small amount of hydrogen that is consumed is generated by the steam reformation of methane, to produce what has been described as blue hydrogen. The by-product of the process is carbon dioxide. The carbon-free generation of hydrogen would depend on the electrolysis of water that separates it into hydrogen and oxygen. This might be best achieved using the power of nuclear reactors in an efficient high-temperature process.

If electricity is bound to become the prime mover of the economy, then its supply must be increased. The Government acknowledges this. Following an analysis of the Climate Change Committee, the recent Energy White Paper has envisaged a doubling of electricity generation by 2050 in the context of a reduction of total energy usage to two thirds of its present level. This seems to be a severe underestimate of what is required.

The Technology of Batteries

Many of the early Edwardian personal carriers, or autocars, were electric vehicles powered by lead-acid accumulators or batteries. They were superseded by petrol vehicles. The battery-powered vehicles were limited in their speed and in their range, and their batteries imposed a weight penalty. However, they are capable of stopping and starting frequently and effortlessly. They survived in the form of milk floats and delivery vans, such as those of Harrod’s department store in the London Borough of Kensington, which silently plied their trade in its affluent residential areas.

The lead-acid accumulators survive in a vestigial form in modern petrol driven vehicles as the means of powering their starter motors. Early automobiles were started with hand cranks, and the electric starter motor began to be adopted in the 1920’s. An early example of a car equipped with an electric starter motor was the luxury Cadillac car of 1912. It was not until the advent of the lithium ion battery that a realistic alternative to petrol powered vehicles emerged.

An electric battery, correctly defined, is a collection of electric cells, although the term is often applied to a single cell. A 12-volt car battery, for example, is made of six cells. A cell consists of two electrodes: an anode and a cathode, an electrolyte surrounding them and a semi permeable membrane separating the electrodes. These components are contained within a casing.

During charging, negatively charged electrons accumulate on the anode while the positively charged ions, from which the electrons have been stripped, accumulate on the cathode. Charging induces a voltage difference between the anode and the cathode.

When an external circuit is created that connects the electrodes, the electrons flow in the opposite direction. The positively charged ions travel through the electrolyte to the cathode to be recombined with electrons. The power of a discharging battery is the product of the voltage difference between the electrodes times the amount of current that is flowing between then (P = I times V). This is the amount of work that the battery is performing.

The processes of charging and discharging can be repeated many times but, eventually, the cells decay. When a lead acid battery discharges, the sulphates in the electrolyte attach themselves to the plates. During recharging, the sulphates move back into the acid, but not completely. Some sulphates crystallize and remain attached to the plates, which means that, over time, less sulphates are available to be part of the chemical reaction by which the battery functions.

Lithium ion batteries are a recent innovation. In the early 1990's, they began to be used in portable electronic devices, such as watches, calculators and laptop computers. The price of lithium batteries has declined by 97% in three decades. The first production car to use a lithium ion battery pack was the Toyota Vitz CVT in 2002. By 2020, there were more than 10 million electric vehicles on the world's roads, with vehicles equipped with lithium ion batteries driving an exponential expansion.

In such batteries, the lithium ions are the charged particles that move between the electrodes. With an atomic number (or proton number) of 3, lithium is the lightest of the alkaline metals. It can lose an electron to become an ion more easily than any other metal. Therefore, its ions move more rapidly in response to an applied voltage. The lightness of the metal also means that lithium ion batteries do not impose the weight penalty of lead-acid batteries.

As a mature technology, Lithium ion batteries have limited scope for significant improvements in their performance, albeit that there remain possibilities for improvements and for increased efficiencies in manufacturing them, including, crucially, the development of the means of recycling their materials. Nevertheless, there is ongoing research into battery technologies, including lithium ion batteries.

One witness has provided an optimistic assessment of the scope for improvements in lithium battery technology. He has proposed that a good off-the-shelf lithium ion battery should provide an energy density of 250 watt-hours per kilogram. He imagines that "more specialist manufacturing" might raise this to 300 watt-hours per kilogram and that, with tweaks to technology and materials, 350 to 400 watt-hours per kilogram could be achieved. These are surely the outer limits.

In the UK, battery research and development since 2017 has been supported primarily by the Faraday Battery Challenge, which is administered by UK Research and Innovation. This is the main public sector funding body for academic and industrial research. The Challenge has invested £318 million since 2017, primarily to set up two new organisations and to fund operations until 2022.

The Faraday Institution funds public sector research projects, and it acts as a central coordinating body for much of the UK's research activity. The UK Battery Industrialisation Centre provides facilities for product developers to trial the manufacture of new batteries. However, the funding is short-term. The Faraday Institution was initially funded for four years up to March 2022, and it is currently bidding for renewed funding.

The funding available for battery research in the UK does not measure up to what is available to other nations. Nevertheless, there is a belief that the UK is well equipped with scientists and scientific knowledge. The importance of the research is that it will enable the nation to keep abreast within developing areas and to have the chance of generating successful innovations, albeit that these are unlikely to result in more than marginal improvements. Nevertheless, such improvements could give significant advantages in a highly competitive international market.

There are also a variety of next-generation battery technologies that are attracting attention. The Faraday Institution funds research that looks beyond lithium ion batteries and which considers alternative battery chemistries. There is bound to be an increasing demand for lithium, cobalt and copper, and cheaper substitutes should be considered.

Sodium, which falls directly below lithium in the periodic table, is a more abundant and accessible metal. Its heavier atomic weight (with an atomic number of 11) makes its ions less mobile, with the result that a battery constructed on the same lines as one using lithium will have a lower energy density. Sodium batteries that are under development typically have ratings of around 160 watt-hours per kilogram. However, there are many applications, both mobile and stationary, where weight and volume are not crucial, which provides scope for such batteries.

Some advantage may result from replacing the liquid electrolytes of the current batteries by solid-state electrolytes, with some improvements in energy density and in the rates of charging. However, it may take a decade or more to achieve a marketable solid-state battery. There is also talk of lithium sulphur and lithium air batteries, which might also achieve higher energy densities, partly by reductions in weight.

The Technology of Fuel Cells

Fuel cells have a much longer history than lithium ion batteries. The fuel cell was invented by Sir William Grove in 1838. The first commercial use of fuel cells came more than a century later following the invention of the hydrogen–oxygen fuel cell by Francis Thomas Bacon in 1932. Fuel cells have been used in NASA space programs since the mid-1960s to generate power for satellites and space capsules.

A fuel cell generates electricity by combining hydrogen, or a fuel containing hydrogen, with oxygen to produce a flow of electrons together with the products of the oxidization, or combustion, of the fuel. If the fuel is pure hydrogen, then the product of its combustion is just water.

The cell has an anode and a cathode. The electrons of a pure hydrogen fuel are stripped away to create ions that are just protons. The electrons travel from the anode to the cathode via an external circuit. At the cathode the ions combine with oxygen atoms from the air to produce the oxide of the fuel which, in this case, is water.

Other fuels that may be used in a cell are ammonia NH_3, methane CH_4 and methanol CH3OH (methyl alcohol). If methane or methanol are used, then one of the products of combustion will be carbon dioxide, whereas, if ammonia is used, the products of combustion will be noxious nitrous oxides. Therefore, the preferred fuel may be hydrogen. Since this gas has a low energy density, it is usually compressed or liquefied. The advantage of employing liquid ammonia as a fuel is that it has a higher energy density than hydrogen.

The ongoing research in fuel cells is aimed mainly at improving their lifespan and at reducing their costs via a more efficient use of materials. As well as producing electricity, fuel cells create heat, which has no use in transport applications. However, the heat might be useful in stationary applications; and fuel cells working at high temperature have a range of potential industrial applications.

The overall efficiency of this means of generating electricity and the amount of the associated carbon emissions depends on how the hydrogen fuel is generated. At present, most of the available hydrogen is generated by the steam reformation of methane, which creates carbon dioxide as a by-product. Hydrogen generated by electrolysis is carbon neutral, albeit that the electricity that powers the process may be associated with carbon emissions. An efficient and a carbon neutral means of generating hydrogen would be by high-temperature electrolysis using heat and electricity generated by nuclear power.

Hydrogen has been proposed as a store of energy. It could be used in mitigating the intermittence of the electricity generated by wind and solar power. For this purpose, the generation of hydrogen by electrolysis and its use in fuel cells for generating electricity could become closely coupled.

Hydrogen fuel cells have been used in a variety of passenger cars that have been manufactured in Japan and South Korea. Currently only two are in production, which are the Toyota Maria and the Hyundai Nexo. Both of these cars are available in Europe, but the lack of refuelling facilities makes them an unattractive proposition. Buses, forklifts and earthmovers that are powered by fuel cells are also available. In the UK, there are two manufacturers of fuel cell buses; and England's first fleet of hydrogen powered double-decker buses are set to be introduced in London.

The Government is likely to provide incentives to bus companies to adopt them in replacement of diesel-powered buses. The advantage of powering a bus by a fuel cell as opposed to a battery is in the long periods between refuelling. Recharging a bus in crowded urban environments is difficult and time-consuming.

Doubts about the safety of hydrogen arise from the memory of the airship disasters in the 1930's, which were due to the flammable nature of hydrogen. However, petrol poses a far greater hazard than hydrogen. If a pressurized hydrogen fuel tank ruptures, the gas vents into the atmosphere, removing the hazard, even if the gas caught fire. Whereas battery power is likely to be preferred for cars and light vans, fuel cells are liable to be preferred, eventually, for HGVs and freight.

The Deployment of Batteries and Fuel Cells in the UK

The UK has domestic targets for reducing greenhouse gas emissions under the Climate Change Act of 2008. The Act established a long-term legally binding framework to reduce emissions, initially committing the UK to reducing emissions by at least 80% below 1990/95 baselines by 2050. In June 2019, following the IPCC's Special Report on Global Warming of 1.5°C and advice from the independent Committee on Climate Change, the Climate Change Act was amended to commit the UK to achieving a 100% reduction in emissions (to net zero) by 2050.

Batteries and fuel cells are expected to play a major role in decarbonising the UK economy. Their principal contributions are expected to be in transport, which comprises passenger cars, vans, heavy freight lorries, rail, shipping, and aviation. There are also contributions that they can make to the reduction of industrial emissions. They might also have a role to play in balancing the supply and the demand for electricity, which is subject to wide diurnal and seasonal variations.

The Government can create incentives for the uptake of these technologies in a variety of ways. It can make financial contributions to research and development. It may make subventions to manufacturers of fuel cells and batteries and to the manufacturers that use them, which are predominantly the manufacturers of vehicles. The Government and other authorities can put restrictions on the use of the modes of transport that give rise to the emissions. Ultimately, they can ban the sales and, eventually, the use of the equipment responsible for the emissions.

Light Road Transport: Cars and Vans

The most rapid progress in the electrification of transport has been in respect of cars and vans. The sales in the UK of battery-powered electrical vehicles appears to be increasing at an exponential rate.

There were nearly 300,000 pure-electric cars on UK roads in May 2021, and more than 600,000 plug-in models, including plug-in hybrids. The current sales of pure-electric vehicles are now equal in number to those of the hybrid vehicles, and they are set to overtake them.

In September of 2021, nearly 15% of new cars sold were pure electric, which was up from 11% in August. Almost 7,000 Tesla Model 3 vehicles joined Britain's roads as the best-selling electric vehicle. A stimulus to the sales of electric vehicles has been provided fortuitously by the shortage of petrol at the pumps, which was due to a shortage of drivers of petrol tankers. In the same period, the number of new cars sold was the lowest since 1998, down almost 45% compared with the 10-year average before the pandemic.

The global motor industry has focused more on battery electric vehicles than on vehicles powered by fuel cells. Most motor manufacturers have added or intend to add one or more battery powered vehicles to their range. In the UK, there are probably no more than 250 light fuel cell vehicles on the roads.

The Government is now keen to encourage the uptake of electric vehicles. It has banned the sale of new petrol and diesel cars and vans from 2030, in accordance with a recommendation of the Climate Change Committee; and it will ban the sale of new hybrid cars and vehicles from 2035. The sale of some hybrid vehicles with large emissions at the tailpipe may be banned from 2030.

There are also signs of a growing uptake of electric vehicles in the bus industry, both for urban transport and for long-distance coaches. There is uncertainty about the appropriate means of powering the buses, albeit that fuel cells afford a longer range than do batteries. Currently, the UK's bus fleet consists of 2% zero emission buses 14% hybrid buses and 84% diesel buses.

The Government is keen to foster a conversion to electric buses. Their ten-point plan of 2020 committed £10 million to kick-start the process and "to begin the introduction of at least 4,000 more British built zero-emission buses." At present, there are two British companies in the market to sell hydrogen buses, which are Wright bus and Ryse Hydrogen. The two companies are now in joint ownership. In March, it was announced that Wrightbus would receive £11.2m from the Government to develop hydrogen-fuel technology.

There is less certainty regarding the electrification of heavy goods vehicles. The Swedish Volvo firm joined with the German Daimler company in 2020 to develop fuel cell systems for use in heavy-duty trucks. The Swedish firm Volta Trucks, which was founded in 2017, is marketing a 16 tonne vehicle, which is powered either by a 150 kWh battery or by a 225kWh battery.

Britain appears to be lagging behind other European countries in this respect. The fuel cell firm Viritech has detailed several hydrogen-fuelled concepts, while expressing concern that the UK could fall behind in the global market for hydrogen, citing a shortage of government funding in the most crucial areas for hydrogen development.

The Government has announced plans to phase out new diesel heavy goods vehicles (HGVs) by 2040, but these plans are currently subject to consultation and they have yet to pass into legislation. The Department for Transport is considering two-stage approach, in which the sale of new petrol-powered and diesel-powered HGVs weighing up to 26 tonnes are banned in 2035, and the sale of heavier vehicles using petrol or diesel are banned in 2040.

Rail Transport

The rail sector in the UK accounts for 1.4% of the transport emissions and for 0.5% of all UK emissions. Therefore, it might be concluded that it is in little need of improvement. However, an enhanced rail service could displace road transport with a consequent reduction in emissions, lasting for as long as it takes to decarbonise road transport. The excellent emissions performance of rail is due in part to the energy efficiency of this form of locomotion and in part to the extensive electrification of the service. That electrification should be extended, and the Government proposed in 2018 that diesel trains should be removed from the network by 2040.

Compared with those of other European countries that developed their rail networks at later dates, the UK system faces greater difficulties in modernizing. The fitting of overhead electric power lines is impeded by the restricted sizes of tunnels and the narrow apertures underneath the bridges that pass over the tracks. An alternative to overhead electrification is to employ trains driven by batteries or by fuel cells. Compared with fully electrified trains, such vehicles are at a disadvantage in consequence of the weight penalties that they incur in carrying their fuel or their batteries. A common judgment is that the program to electrify the UK rail network has fallen behind its schedule.

Aviation

Aviation poses some of the greatest difficulties in pursuit of the decarbonisation of transport. Flight requires fuels of the highest energy density, and this is provided by Kerosene-type jet fuels that are derived from fossilized hydrocarbons. There is a natural unwillingness to abandon the technology of turbine propulsion, which is common to all modern aero engines. Therefore, there is an endeavour to find so-called sustainable aviation fuels that will serve to sustain this technology.

There have been proposals to replace jet fuels, which come from fossil sources, by fuels synthesised from biological materials, which are deemed to be renewable. The object is to create biofuels that can be blended seamlessly with the fossil fuels. The carbon emission from biofuels can, supposedly, be reabsorbed in the growth of their biological feedstocks. The biofuels could be produced from agricultural crops, such as corn, sugar cane or used vegetable oil, and from forestry products.

An objection is that biofuels are liable to be competing for agricultural land with crops for human consumption. Nor is it clear that all of the emissions resulting from their combustion will be reabsorbed in new biological growth. A more radical proposal is that the carbon content of aviation fuels should be provided by the direct air capture of carbon dioxide. Although this is a feasible and a desirable recourse, it would be expensive, and it must be regarded, at best, as a long-term solution.

There have been proposals for powering short haul aircraft by hydrogen fuel cells. Aircraft that demonstrate this technology have already flown. The matter of whether liquefied hydrogen can be used in long haul flight is debatable. On the basis of mass, hydrogen has nearly three times the energy content of gasoline—120 MJ/kg (Mega joules per kilogram) for hydrogen versus 44 MJ/kg for gasoline. On the basis of volume, however, the situation is reversed; liquid hydrogen has a density of 8 MJ/L (Megajoules per litre) whereas gasoline has a density of 32 MJ/L.

Shipping

Fuels for shipping must have a high energy density. At present, diesel oil is used in ships that operate close to shore, while heavy fuel oils, which are dirty and toxic and high in sulphur content, are use in ocean going shipping. Ammonium has been proposed as an alternative fuel for use in fuel cells and even for direct combustion. Danish shipping company Maersk is developing an ammonia engine, but few technical details have been forthcoming.

Stationary applications

Batteries and fuel cells have been proposed for a variety of applications that are not associated with transport. The use of batteries as storage devices for the electrical power grid has been proposed to compensate for the intermittence of renewable power generation.

It has been suggested that, when a large number of batteries reside in electric vehicles, they would be available for the storage of electricity. This proposal does not survive closer examination. The vehicles are liable to be in use at times when there is a high demand for electricity, making their storage capacity unavailable to the grid. Moreover, the storage capacity of batteries is limited. However, there are currently some examples of large-scale battery storage, such as 20-megawatt battery, located in Carnegie Road in Liverpool.

Batteries may have a role in addressing the short-term fluctuations in the grid supply, where the voltage must be kept within a narrow band. Their power can be deployed rapidly for this purpose, which may be served better by batteries than by hydro electricity that depends on the pumped storage of water.

Fuel cells coupled with a plentiful reserve supply of hydrogen would be a more appropriate means of generating electricity to overcome the diurnal and seasonal variations in the demand for electricity as well the variability in its supply from renewable sources. The hydrogen needs to be generated in a manner that is not associated with emissions. A combination of renewable power and nuclear power could be relied on to provide the electricity to be used in generating the hydrogen by the electrolysis of water.

Batteries and Fuel Cells in the UK Economy

The UK Government has been at the forefront in declaring targets for the reduction of CO2 emissions and other greenhouse gasses. The Climate Change Act of 2008 made it the duty of the Government to ensure that the net UK carbon emissions for all six Kyoto greenhouse gases for the year 2050 should at least 80% lower than the 1990 baseline.

An independent Committee on Climate Change was created under the Act to provide advice to UK Government on these targets and on related policies. The Bill was enacted by a Labour government, and it acquired the assent of politicians from across the range of political parties. Its objectives have been adopted by succeeding governments.

In April of 2021, the Government set in law the target of cutting emissions by 78% by 2035 compared to 1990 levels. This would bring the UK more than 75% of the way to net zero by 2050. It was claimed that the UK would be going faster in the direction of zero emissions than any comparable nation. However, in the opinion of many experts, the Government has not established adequate means for achieving such targets.

It is notable that the political party that forms present government has been traditionally opposed to state intervention. Ministers appear to believe that the setting of targets and the imposition of restrictions that prevent the sales of polluting vehicles after certain dates should be sufficient to ensure that the targets will be met. They have also provided support to stimulate research and to encourage the manufacture of low emissions equipment.

However, in the opinion of the Science and Technology Committee, none of this measures up to the magnitude of the task ahead. The funding that has been made available for addressing the problems of climate change by governments of other nations exceeds what has been made available in the UK, both in absolute terms and in proportionate terms.

The manufacturing sector in the UK is now so attenuated that it can no longer be expected to rise to the opportunities that are afforded by the banning of the sales of polluting vehicles. The likelihood is that such restrictions will lead to the importation of compliant vehicles and to the demise of British motor manufacturers.

The automotive sector around the world is investing heavily in faculties to manufacture the batteries to meet the demand for electric vehicles. The Committee was told of the global plans to build so-called gigafactories to meet the demand. China has planned to have 149 gigafactories by 2030, the EU plans 19, for the USA it is 12 and for the UK it is 2. However, the Faraday Institute has predicted that the UK will need 8 gigafactories by 2040.

The same deficiencies are apparent in the Government's approach to the future of fuel cell technology. The Government has paid far less attention to fuels cells than it has paid to batteries. This relative neglect is reflected in the report of the Science and Technology Committee, which is in spite of the major role that fuel cells must play in a green industrial revolution.

The support of the UK Government for fuel cells technology appears to be insignificant beside the support that has been provided by other European Governments. The UK Government has undertaken to devote, probably, no more than £250 million to fuel cells, whereas the amount forthcoming from the German Government for the support of a hydrogen economy may amount to as much £9 billion.

Evidence of the limited support of the UK Government for the hydrogen economy can be gathered by trawling through a document titled UK Hydrogen Strategy. The document indicates the extent to which the Government will be relying on the initiatives of the private sector. It declares the ambition that, by 2030, the low carbon hydrogen production capacity should reach 5GW (gigawatts). This amount of power can be compared with the installed generating capacity of the UK electricity sector, which was estimated in 2021 to be 75.8GW.

The obstacles that have to be overcome by a successful fuel cell strategy are far greater than those affecting the battery strategy. Battery powered vehicles can be recharged from power points that are attached to the existing electrical supply network. Until such vehicles become numerous, there will be no need to adapt this grid to meet the extra demand.

By contrast, fuel cell vehicles demand completely new infrastructure to supply their fuel. This is expected to arrive, in the first instance, in bus and freight depots. Only at a later stage will the refuelling be provided in the forecourts of the erstwhile petrol stations, which will have been largely converted for the recharging of battery-powered vehicles.

The matter of the availability of the hydrogen is also a cause for concern. The quantities that are predicted to be available by 2030 appear to be very limited and it is unclear how they might be generated. The Hydrogen Strategy proposes an approach that combines the production of hydrogen by the steam reformation of methane with carbon capture together with its production by electrolysis powered by renewable energy.

Although the steam reformation of hydrogen is to be regarded as a temporary expedient, the capture of its carbon by-product would rely on technology that has yet to be fully developed. Both methods of generating the hydrogen are energy intensive, and there may be doubts concerning the availability of the energy.

Future Demands for and the Supply of Electricity in the UK

The title of the Government's Energy White Paper is Powering Our Net Zero Future. It addresses the need to staunch our emissions of carbon dioxide in view of the advancing crisis of climate change.

It proposes that, by 2050, we should double our generating capacity for electricity, while reducing our overall energy consumption to two-thirds of its present level. This is a gross underestimate of our requirements for electricity and power. According to a widely accepted analysis, the electrification of transport alone would require a 75% increase in generating capacity. See Doros, (2018). The decarbonisation of the economy will create numerous additional demands, and the only source that could meet them is nuclear power.

There are numerous industrial processes that need to be decarbonised. They include the manufacture of steel and cement, both of which are energy intensive and both of which could be powered by electricity. Synthetic fuels that incorporate a carbon content that has been captured from the atmosphere could replace existing hydrocarbon fuels, but their manufacture would also be energy intensive. Industrial processes that require heat could become reliant on hydrogen, but this would need to be generated using electrical power.

The Government appears to favour renewable sources of electricity. The large electricity companies have shown themselves to be willing and able to invest in wind-generated electricity; and the costs of this has fallen markedly over time. However, given the intermittence of these sources of power, there is a limit to the extent to which they can be relied upon without the support of an ancillary system to back them up.

Hitherto, the back-up for renewable energy has come from coal-powered electricity and from electricity generated by combined-cycle gas turbine power plants. Both of these sources generate carbon emissions and they must be replaced. Either alternative sources of power must be utilised or else the energy from renewable sources must be stored to be available to meet the deficits.

The only viable alternative source of power that is carbon neutral is nuclear energy. An appropriate store of energy is hydrogen, and the energy of the hydrogen would be best recovered as electrical energy by means of fuel cells. Fuel cells could be closely coupled with the facilities for generating and storing the hydrogen. Moreover, the hydrogen would be generated most cheaply and efficiently by high temperature electrolysis using the heat and the power of nuclear reactors.

The recent history of civil nuclear power in the UK has been one of repeated failure, in which projects to build new power stations have failed to materialise. The coalition government of Clegg and Cameron recognised the need to renew Britain's fleet of nuclear reactors, and, in 2010, it was agreed that the construction of 8 new nuclear reactors should be called for. The new nuclear power stations were to be built near existing sites in Bradwell in Essex, Hartlepool, Heysham in Lancashire, Hinkley Point in Somerset, Oldbury in South Gloucestershire, Sellafield in Cumbria, Sizewell in Suffolk and Wylfa in Anglesey.

However, in March 2012, two of the prospective developers, who were RWE npower and E.ON, announced they would not be constructing new nuclear power plants. Their decision followed a similar announcement by Scottish and Southern Electricity the previous year. Hitachi purchased the Horizon joint-venture, intending to build two or three 1350 MWe Advanced boiling water reactors (ABWR) at Oldbury and Wylfa.

In November 2018 Toshiba, which had planned to construct a reactor at Moorside in Cumbria announced its withdrawal from the development. Then, in January 2019, Horizon Nuclear Power, which was the consortium led by Hitachi, suspended the project to build reactors at Oldbury and Wylfa. This left the French company EDF as the sole nuclear contractor.

EDF are involved in the construction of the Hinkley C power station, which began in December 1918, after some hesitation from the government of Theresa May. They are vying to construct another power station that would be a replica of Hinkley C and which would be described as Sizewell C. EDF has also proposed to build another replica at the Moorside site that has been abandoned by Toshiba.

The China General Nuclear Power Group (CNNC) has a financial stake in the Hinckley C project amounting to 33.5%, and it has been proposing to build a reactor to a Chinese design at Bradwell. CGN would take a 66.5% majority share and EDF would have a minority share. It has been reported that the Government wish to limit the involvement of CGN and the Chinese state in the UK nuclear industry. However, the Government has not said anything officially, and the project is still active.

Whereas the Government wholly financed the Britain's original nuclear power stations, in recent years there has been an expectation that the private sector can be relied upon to undertake and to finance investment in the power supply. This expectation has been supported by the success of the private sector in building the combine-cycle gas turbine power stations that have exploited the availability of North Sea Gas and which have largely replaced Britain's coal-fired power stations. It has been further strengthened by their success in constructing wind turbines for generating electricity.

A problem affecting private sector projects to build nuclear power stations is that no revenues will be forthcoming for as long as it takes to complete the construction. This period may be as long as ten years. The firms and the consortia that have been proposing the projects have been unable to raise the necessary capital from the financial markets to supplement their own limited resources. The high rates of interest charged for borrowing the funds are liable to make the projects to build nuclear power stations unsustainable.

The capital funds that are borrowed from the financial markets must be repaid eventually. The repayments are burdened by surcharges. The first of these arises from a discount factor that is applied to future repayments that are valued at less than present payments. The second surcharge is a risk premium that is charged by the lenders as an insurance against the eventuality that the repayment will not materialize. Finally, to encourage the funds to be forthcoming, it may be necessary for the borrower to pay a scarcity premium.

These three surcharges can be reduced if the Government undertakes to finance the project. The Government will be able to borrow the funds without paying a risk premium, under the supposition that it does not default on its debts. If the funds are not readily forthcoming from the financial markets, then the Government may resort to creating the money to enable it to pre-empt the resources that will be demanded by the project. Finally, a Government that is intent on an enduring social investment may wish to discount its future benefits, to a lesser extent than lenders within a financial market would discount them.

Therefore, nuclear projects would be better financed directly by the government rather than by the private sector. This has not happened for reasons that are due partly to the free-market philosophy of the present Government. There has also been reluctance on the part of the Government to increase the public sector borrowing requirement by the costs of infrastructure projects. Instead, there have been attempts to create sufficient inducements to encourage the private sector to undertake the investments.

The first attempt at creating the necessary inducements was via a system of so-called contracts for differences, which promised sufficient payments to the constructors and the operators of nuclear power plants to cover their costs. Guaranteed payments were entailed in the so-called strike price. Any returns to the investment that were below the strike price would be supplemented, and any returns that were above it would be taxed.

The system of contacts for differences has failed to bring forth sufficient investments, and it is due to be replaced by another system known as a regulated asset base. This new regime, which has yet to be enacted in law, will allow the constructors of nuclear power plants to impose a levy on consumers of electricity, during the period of construction when there will be no other returns.

Alternative ways of raising the finance, which do not appear to have been considered by the Government, are either to finance the projects by the issuance of designated bonds, backed by the security of the Government, or else to create a supply of funds to enable the project to preempt the necessary resources by increasing the supply of money. Meanwhile, those who see the need for immediate action to revive Britain's nuclear program are awaiting the outcome of the latest attempts to raise the necessary finance with mounting exasperation.

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