PICKING WINNERS

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The Global Warming Policy Foundation
Briefing 70

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Contents

About the author

After graduating in chemistry, Martin Livermore worked for Unilever, Dalgety and DuPont for 27 years in a range of technical jobs in the food and agriculture sector, in the UK, South Africa and the Netherlands. He set up his own consultancy business in 2001, working with national and international trade associations and major companies on a range of science communications issues, while developing particular interests in the biotechnology and energy sectors. He was director of the Scientific Alliance from 2006 until 2018, working to encourage a rational, evidence-based approach to major policy issues.


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Summary

Nearly all technologies that have been commercialised have achieved success via market forces: they have provided consumers with some new or additional benefit at a price that offers value for money. Governments, on the other hand, are prone to pick on what they are advised (not always strictly objectively) is the best available technology to achieve a particular policy goal. They then back it to the exclusion of others. But picking winners is seldom successful.

This study reviews a range of projects from the last few decades in the UK – some successful, some not – and summarises the factors contributing to their success or failure. These are:

- Concorde
- The replacement of filament lamps by LEDs
- Nuclear power
- Mobile phones
- HS2

Unfortunately, politicians have not learnt the lessons of these case studies and are in the process of repeating mistakes in the race to achieve Net Zero with current technologies. This study reviews, in particular:

- electricity generation and storage
- carbon capture and storage
- heat pumps for domestic heating
- battery electric vehicles as replacements for the internal combustion engine.

In each case, top-down targets have been set and a predetermined route set out, with taxpayers' money used to drive consumer acceptance of technologies that are otherwise uneconomic. This study argues that a far better use of resources for both the UK population and, in the longer term, for citizens across the world, is to set broad top-level goals and enable competition between technologies and companies so that better, more economic solutions can be developed.

Introduction

Although fortunately not taking things to the extreme of the Soviet planned economy, all governments try to achieve particular economic or political ends by interfering in free markets from time to time. Admittedly, allowing Adam Smith's 'invisible hand' completely free rein will not always be for the greater good of society, but appropriate regulation is normally enough to allow for the development of a competitive market that lets innovation proceed, as well as providing stable supplies of established goods. In this environment, new technologies can be – and are – commercialised, allowing consumers to determine their market success or failure. New technologies take over because they offer advantages to consumers; in the words of Sheikh Yamani 'The Stone Age came to an end not for a lack of stones, and the oil age will end, but not for a lack of oil.'

The UK was the first country to make achieving drastic decarbonisation of the economy a legal requirement (although in practice this means no more than allowing well-funded court cases to embarrass future governments). The 2008 Climate Change Act obliged the government to reduce net emissions of greenhouse gases by 80% over the 1990 baseline by 2050. More recently, the target was revised to 100%. Legislating for Net Zero was essentially an act of faith, because the technology to achieve it in an economically acceptable way did not exist. Nor does it exist now, but that makes no difference to official policy. The rational course to take in this situation would be to encourage the open and competitive development of new, improved or less costly ways to reduce emissions. Instead, the choice has been to set dates for the phasing out of efficient existing technologies while dictating their replacement by what are deemed to be the best available alternatives.

Thus, faith is being placed in solar and wind energy to supply the bulk of our energy needs, the sale of cars with internal combustion engines (and even hybrids) will be banned from 2035, and no new gas boilers can be installed from 2035 (2025 for new-build homes). People needing to change their cars will only be able to buy fully electric vehicles, while homeowners will have a choice of heat pumps, electric heating or, possibly, hydrogen-fuelled boilers. In a free market, these technologies would struggle to make much impact at present, but government policy gives people no choice.

At some stage, of course, unrealistic targets will encounter the realities of life. People will be unable to afford the changes, many of those who can will be dissatisfied, and targets will be missed. Any mainstream political party offering a way out of this mess would rapidly gain support, as the 'winners' picked by politicians turn out to be losers. This paper describes some of the losers picked in recent history, and also outlines the technologies that it is hoped will be the winners on the road to Net Zero. It is to be hoped that future governments will learn from the mistakes of the past rather than repeating them.

Concorde

Concorde, the first and, so far, sole supersonic commercial passenger plane, was a joint UK/French government venture designed essentially as a prestige project that would help support and boost domestic aerospace companies. BAC and Sud Aviation had discussed the project as early as 1961, and the following year a draft treaty was signed as a commitment to Anglo-French state funding for the development costs.

In the early 1960s, jet airliners had become quite common. The De Havilland Comet, the world's first commercial jet, had entered service in 1952, and was joined by the Boeing 707 and Douglas DC-8 in 1958. The USSR had effectively launched the Space Race just a year before, with the launch of Sputnik 1. After the devastation of the Second World War, economic growth was strong, oil prices were low, and most people were unquestioning about the benefits technology could bring. Against this background, development of a supersonic airliner must have seemed an almost inevitable step.

In January 1963, President de Gaulle first mentioned Concorde as the name of the new aircraft; initially the UK government under Harold MacMillan decided that the English version of the spelling should be Concord. In June that same year, the US airline PanAm signed sales options for six planes and President Kennedy announced backing for an American supersonic commercial jet. Harold Wilson's incoming Labour government announced it would withdraw from the Anglo-French project later that year as part of a programme of cost savings. However, political pressure trumped economics and the decision was reversed in January 1964.

Progress during the 1960s was quite rapid. Work on the airframe started in September 1965 and prototype construction began the following year. By May 1967, 16 airlines had agreed 74 sales options and in December a prototype (001) was unveiled. Meanwhile, on New Year's Eve 1968, the Russian Tupolev Tu-104 flew for the first time, enabling the USSR to claim the first flight of a supersonic airliner. Concorde/Concord was in competition with the two world superpowers, and a bright future apparently beckoned for supersonic travel.

The first two Concordes flew in early 1969 and the first pre-production model (01) flew in December 1971. The following year, 16 production aircraft were authorised; BOAC ordered five and Air France four, with preliminary orders from other airlines. At the end of the year, the UK government (now under Edward Heath) raised the amount of the production loan approved from £125 million to £350 million (in 1972 prices). Costs were beginning to escalate sharply.

In October 1973, OPEC (the largely-Arab Organisation of Petroleum Exporting Countries) proclaimed an oil embargo against countries that had supported Israel during the Yom Kippur war earlier that month. Oil prices rose 300% and transport in the UK, USA and elsewhere was disrupted as fuel supplies were interrupted. There had already been serious doubts about the commercial viability of Concorde. The US Congress abandoned funding for the American project as early as March 1971 and in early 1973 PanAm, TWA, American Airlines and Continental had all decided not to take up their purchase options. A quadrupling of the oil price apparently sealed the aircraft's fate.

At this stage, many politicians might have decided to cut their losses. However, in July 1975 Prime Minister Harold Wilson and President Valéry Giscard d'Estaing agreed to continue with Concorde, but to limit production to 16 planes. It is worthwhile looking further into this decision, particularly because Wilson, as incoming prime minister, had announced his government's intention to exit the project, as part of a range of cuts to ease the inherited balance of payments deficit. The rapid reversal of this decision hinged on the fact that the British and French governments had not simply entered into a commercial agreement but, in 1962, had signed a binding treaty. The financial penalties of withdrawal were deemed to exceed the costs of proceeding.[*] It appeared that the political and technological aspects of the cooperation outweighed the economics.

The UK aeronautical industry was technically strong, but had no recent experience of building passenger aircraft. The USA was unwilling to cooperate on the development of a supersonic passenger jet, and the UK was unlikely to be able to compete alone. In France, on the other hand, the aircraft industry had stagnated during the years of occupation and wanted to pull in technical expertise to enable it to build a dominant position in Western Europe. Britain in the early 1960s had applied to join the Common Market (the forerunner of the EU) and was drawn into what became the Concorde project in part to strengthen ties with France. That this cooperation was enshrined in a treaty demonstrated the commitment of both parties, but made dropping out extremely difficult. The fact that President de Gaulle vetoed Britain's membership of the Common Market is yet another demonstration of the deep cynicism of political leaders.[†]

So, the UK government found itself effectively trapped, committed to the continued funding of a project of doubtful economics at a time when it was struggling to cut expenditure. However, for some, prestige and politics overshadowed mere economics. In May 1974, when the Labour government was agonising about the project, and a year before it

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[*] A Treaty too far? Britain, France and Concorde, 1961–64; Lewis Johnman, Frances MB Lynch; *Twentieth Century British History*; Vol 13, Issue 3, 2002; pp.253–276; https://doi.org/10.1093/tcbh/13.3.253

[†] The Road to Concorde: Franco-British Relations and the Supersonic Project; Lewis Johnman, Frances MB Lynch; *Contemporary European History*; Vol 11, No 2 (May 2002); pp. 229–252; https://www.jstor.org/stable/20081830

was agreed to continue but to build only 16 planes, Tony Benn (then Secretary of State for Industry) presented a supportive paper to the cabinet.[‡] This included the statement that 'Concorde is the finest aircraft ever built' and claimed that supersonic travel was here to stay. But perhaps the most telling section dealt with national prestige and pride:

> We shall never know precisely how our people feel about Concorde until it really is cancelled… After the steady decline of recent years in our fortunes this might be the final straw in self-denigration. And if the French went on with it, flying our Concorde under the Tricolour alone, the wound would not quickly heal.

What difference it would have made to Britain's image as a technology leader or to its 'soft power' if the project had been cancelled at this stage we shall never know.

Against this background, the project went on in a limited way and British Airways (BA) at least found the London-New York route to be profitable, but only because a large part of the development costs of the aircraft had been paid for with taxpayers' money. The 'win' of Concorde was a very limited one; the prestige of building the world's first supersonic airliner, operated by the national flag-carrier.

In January 1976 BA started commercial flights to Bahrain, and Air France to Rio via Dakar. Transatlantic services started in May of the same year. As had become clear, Concorde could only operate at supersonic speed away from land because of the sonic boom associated with travelling at such speeds. This seriously restricted potential routes and, by 1982, the aircraft operated only across the North Atlantic. The airlines were able to make this route pay by charging high fares for a unique and supposedly luxury experience, but UK and French taxpayers covered the development costs. It was clear that Concorde was a one-off, but it continued in service until October 2003. Its withdrawal was hastened by a crash on take-off in Paris in July 2000, killing 113 people.

The ultimate cancellation of the Concorde project represented acceptance of the fact that there was at best a limited niche for commercial supersonic aviation, a fact that had been recognised much earlier in the USA. A clear lesson from this programme is that there is a real danger in pursuing such a project beyond the point where it is obvious that it cannot be commercially viable, whatever the political downside. The lesson is very pertinent to the case of HS2 (see below).

Domestic lighting

In 1879, Thomas Edison patented the incandescent light bulb. Tungsten filaments were introduced in 1904 and the use of inert gas to fill bulbs in 1913 was essentially the last major development of the light bulbs still in use today. When energy prices were low, the fact that such bulbs are only about 10% efficient (with the rest of the electricity producing heat) mattered relatively little. Mercury and sodium discharge lamps were developed as longer-life alternatives for street lighting. However, fluorescent tubes, introduced in the 1930s, represented an alternative that was about three times as efficient, had a long service life and were also suitable for indoor use. By the 1950s, they were widely deployed for lighting commercial premises and also for some domestic uses, such as kitchens and garages. However, their physical size and inflexibility, the rather harsh light quality and their inherent flicker made them unsuitable for most in-home lighting applications.

In order to make fluorescent lighting more flexible for general use, compact fluorescent lamps (CFLs) were developed. In December 2008, the UK (still an EU member state at the time) committed to phase out incandescent bulbs over a number of years, starting in September 2009. Essentially the only alternative at the time was the CFL, which, like its larger predecessors, suffered both from the poor quality of the light produced and also from taking a significant time to reach full brightness. For this reason, many people stockpiled filament

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[‡] Retrospective: When Concorde wasn't the UK's cup of tea; David Kaminski-Morrow; *Flight Global*, 9 April 2019; https://www.flightglobal.com/strategy/retrospective-when-concorde-wasnt-the-uks-cup-of-tea/132222.article

bulbs before their phase-out rather than move to CFLs. In 2010, a research briefing produced by the House of Commons Library noted this, and two other issues associated with this change: the sensitivity of some people to the UV radiation from CFLs and also the potential risk from their mercury content.§

In fact, in 2007 the UK government had already come to a voluntary agreement with retailers to end the sale of filament bulbs by 2011. Two schemes were introduced to encourage the replacement of tungsten filament bulbs with low-energy alternatives: The Carbon Emissions Reduction Target (CERT) and the Community Energy Savings Programme (CESP).

CERT, which ran from April 2008 until December 2012, set the parameters for improving the energy efficiency of households to meet commitments set under the Climate Change Act. CESP was a specific policy to improve energy efficiency in the most deprived areas of the country, and ran from October 2009 until December 2012. Other government initiatives followed, including the Energy Efficiency Commitment (EEC) and Energy Company Obligation (ECO). Although having the same broad objectives, the details differed. This is a good illustration of the tendency of policymakers to over-complicate. In all cases, the responsibility for delivery fell to energy supply companies.

Most of the energy savings were made, not surprisingly, via such things as loft and cavity wall insulation. However, energy suppliers also distributed large numbers of CFL bulbs to help fulfil their obligations. In other cases, retailers subsidised sales to encourage take-up. Many householders will have some of these bulbs sitting at the back of a cupboard, after finding that they were not an adequate replacement for filament bulbs. Today it is rare to find such bulbs in use except occasionally for background or security lighting. Instead, they have been replaced by the yet more efficient, and highly flexible light-emitting diode (LED) technology. People have been willing to pay significantly higher prices for lamps that save considerable amounts of money and last for many years. The market has chosen, not politicians.

If the planned phase-out of tungsten filament bulbs had simply been signalled well ahead, without legislating for a specific path via instruments such as the Carbon Emissions Reduction Target, arguably we would have been in exactly the same position today, but without the stock of unused CFL bulbs. The benefits of LED lighting have become so obvious that they are increasingly replacing fluorescent tubes, themselves considered a low-energy option only a decade or so ago. There was no need to pick a winner; one emerged from the market.

LED lamps provide the quality of light that people like, are cool-running and long-lasting. Manufacturers typically claim an average 50,000 hour life, equivalent to 17 years if used for eight hours a day. Although their cost is higher than filament bulbs, the savings of reduced energy use soon compensate for this. A 2023 publication from the Department for Business, Energy and Industrial Strategy claimed households could save £2–3000 over the lifetime of a set of bulbs. For example, if we assume a home in which eight 60-watt filament bulbs, used for an average of four hours a day over a year, were replaced by 6-watt LEDs, using electricity priced at 20 pence per unit, a savings figure of just over £2,000 is made over 17 years. This is a clear win for the consumer and, not surprisingly, local authorities are increasingly turning to LEDs to replace discharge lamps for street lighting.

Nuclear power

The story of nuclear power in the UK is very different from the first two case studies. This was not a vanity project, nor was it a top-down attempt to force a change to an unsuitable technology.

The UK was one of the early adopters of electricity generation from nuclear fission, having developed a considerable body of expertise during and after the World War II. Nevertheless, the fleet of power stations operational at its peak consisted of a range of non-standard designs, some presenting significant problems. The most successful – Sizewell B – was in fact a non-UK

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§ The phasing out of incandescent light bulbs; SN/SC/4958; Louise Smith; 23 June 2010. https://researchbriefings.files.parliament.uk/documents/SN04958/SN04958.pdf design. In the meantime, France (supplier of the Sizewell B station) built a large fleet of nuclear power stations to a standardised design, which successfully and economically provided the bulk of the country's electricity needs for several decades.

The UK became an early adopter purely because it was one of the first countries to develop a nuclear weapons programme. About 40 British scientists had worked on the Manhattan Project, which resulted in the development of the first atomic bombs, including those used on Hiroshima and Nagasaki. The Atlee government continued the work on nuclear energy (encompassing both military and civil uses), and made a formal decision to build a nuclear bomb in 1947, after the US Congress had made it illegal to share nuclear technology with any other country, including allies.

The UK government took the decision to develop an atomic bomb based on plutonium-239 (the other option was to produce enriched uranium high in the uranium-235 isotope). This drove the design of the first atomic reactors built at Windscale in Cumbria; the aim being to irradiate uranium-238 to produce the necessary weapons-grade plutonium. Uranium was purified and formed into fuel rods in Springfields in Lancashire, the site of a former poison gas factory. Two nuclear reactors were built at Windscale (near Sellafield, the name now used for the entire expanded complex), together with all the downstream processing plant necessary to extract and purify the plutonium for bomb-making.

With work having started in 1947, the two initial reactors were critical by 1951 and the first test of a British atomic bomb, using plutonium from Windscale, was carried out in October 1953. The reactor design team decided to use gas rather than water cooling for good, practical reasons: it avoided the need to have very large quantities of pure water and the potential for loss of coolant. At the same time, work was progressing on the use of enriched uranium for both weapons and as a commercial source of electricity; a plant was built at Capenhurst. Nevertheless, the design chosen for the first reactors that would deliver electricity to the grid (while also producing more plutonium, by then destined for thermo-nuclear weapons) was effectively an improved version of the original Windscale piles. This was christened the Magnox design. The first two were built at Calder Hall in Cumbria, coming on-stream from 1956. These reactors were followed by six more of the same design; two at Calder Hall and four at Chapelcross near Dumfries.

This was a time of high expectations for the future of nuclear power. A White Paper published in February 1955 laid out the government's programme for the Magnox stations, followed by a further series of either gas- or liquid-cooled reactors. It seems that the White Paper was heavily influenced by the desires of the UKAEA (UK Atomic Energy Authority) rather than the CEGB (Central Electricity Generating Board) who would be responsible for running the power stations.

The decision to go ahead with more Magnox stations (at Oldbury and Wylfa) while what became the AGR (Advanced Gas-Cooled Reactor) was fully developed was taken by the CEGB under the leadership of Sir Christopher Hinton. Although the gas-cooled designs were progressing and larger stations were being built, there remained doubts about their relative inefficiency compared to conventional power generation. Hinton suggested that the government consider alternative designs, including the Pressurised Water Reactor (PWR) and Boiling Water Reactor, both developed in the USA.

In the event, this idea was vociferously opposed by the UKAEA, and the Government decided to proceed solely with the gas-cooled route, largely, it would appear, because of the sunk cost argument. Although the Magnox and AGR programmes continued (albeit with delays and cost overruns) and provided a fleet of nuclear power stations that (mainly) operated reliably for many decades, this decision was arguably the first step towards the UK becoming less enthusiastic about nuclear power, having been at the forefront in the early days.

The key advantage of the AGR reactor over earlier Magnox designs was its higher CO_2 exit temperature, and hence significantly greater thermal efficiency. It was also designed to be capable of on-load refuelling, although in practice this was never possible. In May 1965, the government announced the intention of the CEGB to award a contract to build the first AGR at Dungeness B, to the dismay of many in the industry. The consortium awarded the contract – Atomic Power Construction (APC) – went into liquidation after four years, and the planned construction and commissioning period of five years eventually lasted 20. This was effectively the nail in the coffin of the UK's nuclear ambitions.

Four more power stations – each with two AGR reactors – were ordered before the fiasco of Dungeness B became apparent. The two at Hartlepool and Heysham again took around 20 years to build; Hinkley Point B and Hunterston B were still significantly delayed, but took only half the time to build. The two pairs of stations were built by two different consortia to different designs and have suffered from a variety of problems, in particular with the boilers at Hartlepool and Heysham. The lack of a standardised design meant that each station was effectively a first of kind, with all the associated teething problems.

Despite this sorry history, two more AGR-based power stations were started in the 1970s: Heysham 2 and Torness. It seems that this decision was taken primarily to maintain a viable UK nuclear industry. However, finally, after a long public enquiry during the 1980s, the first Pressurised Water Reactor, Sizewell B, was built and began to deliver electricity in 1995. This was the first such design in the UK, built to what was becoming an internationally standardised design. It has operated consistently well.

Following this came the long hiatus in UK nuclear new build and increasing concerns, from some quarters, about nuclear power in general, particularly following the Chernobyl and Fukushima incidents. Although we are presently in a new phase of construction, with Hinkley Point C and the projected development of Sizewell C (both PWRs), this is a difficult time for the industry globally and progress and costs so far have been disappointing, to say the least.

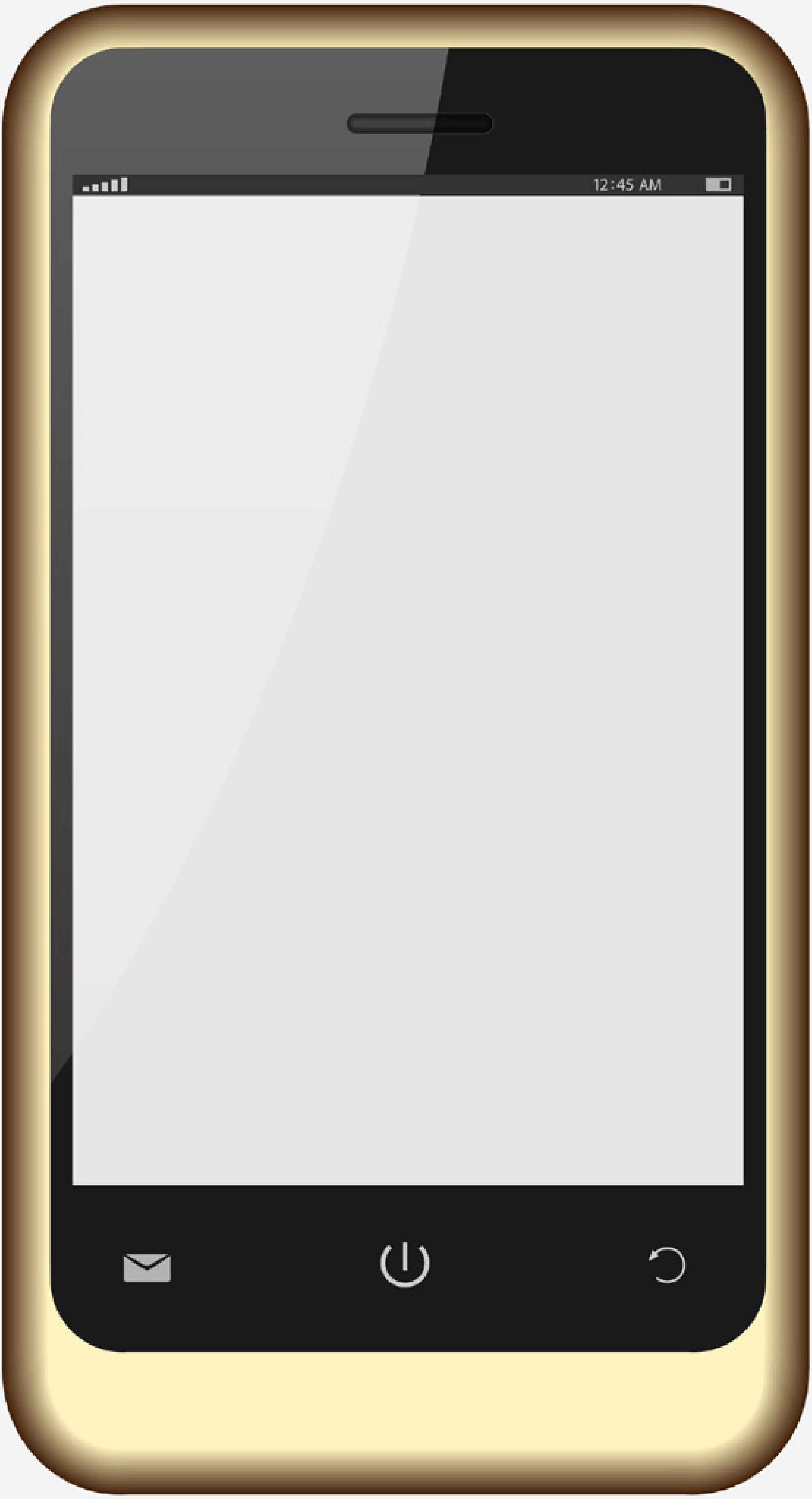
What lessons can we take from this story? The first is that the sunk cost argument should be avoided as far as possible. Politically, abandoning a project that has cost a lot of money may be difficult to sell, even if it makes economic sense, but we elect politicians to spend our taxes as wisely as possible, not to avoid embarrassment. Secondly, although the instinct to continue developing a home-grown technology, which may have export potential, is in principle sound, there must also be a degree of objectivity to ensure that this is not a cul-de-sac, as gas-cooled reactors turned out to be. Finally, the failure to develop a standard design before upscaling led to a range of approaches and no economies of scale.

Mobile phones

The areas we have looked at so far are classic examples of governments backing technologies that turned out to be failures in the marketplace. Let us consider, in contrast, an area where successful development has been entirely a function of free-market innovation driven by demand. Mobile phones have transformed daily lives across the world since their introduction only 40 years ago (the first analogue mobiles appeared in the USA in 1983, and then spread to the UK, France and Germany over the following three years). The first phones were large, heavy and capable only of making and receiving calls, but were enthusiastically taken up by early adopters. The closest to a fully mobile phone previously available was the car phone, which could be used only in a vehicle.

Apart from their unwieldiness, early phones suffered from being analogue devices, so they could be easily hacked. In the early '90s the first digital GSM (Global System for Mobile) phones were launched, aimed at business users. In the UK, two new licences for digital mobiles were offered by the Government, with Orange and One2One being the successful bidders. With these, the market for consumer mobiles was launched. Early phones had monochrome screens but, as well as calls, supported text messaging (SMS). This add-on proved enormously popular, particularly with young people, allowing cheap and rapid communication from almost anywhere. Calls, at this stage, were still quite expensive.

The introduction of WAP (Wireless Application Protocol) at the turn of the century made possible limited internet use on mobiles. This was soon followed by full-colour displays and integrated cameras. In parallel, Blackberry devices focussed on mobile emails; with their distinctive mini-keyboards, they quickly became a must-have corporate status symbol. Then, in 2007 came the big game changer: the launch of the first iPhone.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This was effectively the start of the smartphone era, with the rapid development of competing iOS- and Android-based devices (and even Windows mobile for a time). Today, just thirty years since GSM phones first hit the market, smartphones are ubiquitous, providing full internet access, sophisticated cameras, voice recording and all the functionality of a desktop computer for a few hundred pounds' investment and a few pounds of ongoing cost per month. Unlimited phone calls and SMS messaging are basically free extras bundled into mobile data packages. We still refer to these devices as phones, but they are essentially fully-fledged microcomputers.

All this has been achieved with minimal involvement from governments, their role mainly limited to making available selected parts of the wireless spectrum to providers. For each generation of technology, companies (or consortia) have bid for these as they have become available, largely to provide better and more widespread reception for users. The most recent auction in the UK for parts of the 700-MHz and 3.6–3.8-GHz bands raised £1.3 billion in licence fees from EE, Hutchinson 3G UK (the Three network), Telefonica UK (O2) and Vodafone. This, however, was a small amount compared to prices paid for initial access to the market from the first digital network (2G) operators and, indeed, for most of the spectrum auctions since.

National governments (and taxpayers) have benefitted from the licence fees paid by mobile phone network operators, the operators have funded the rollout of transmission masts and other infrastructure, and the general public and businesses have been happy to pay the prices necessary to keep these operators profitable. The net result is that we pay a smaller and smaller amount for more and more; most people have no need to spend more than £10 a month to have full access to the internet and their networks anywhere there is a signal. There was no need to back winners, only to facilitate their development.

HS2

A Channel tunnel, linking the UK and France, was first mooted in the early 19th century. Construction started in 1988 and the link finally opened in 1994. The dual tunnels – one in either direction – provide a rail link for both foot passengers (Eurostar) and cars and lorries (Le Shuttle). Motor traffic still boards trains at the Folkestone terminal and leaves the train at Coquelles, but passenger trains link London directly with Paris and Brussels. In France and Belgium, the Eurostar trains are able to travel on high-speed lines, but Eurostar originally left London from the Waterloo terminal and ran on the existing railway line, shared with commuter trains and not capable of high-speed use.

After many delays and financial problems for both the construction consortia and operating companies, the first section of a new high-speed rail link between the Folkestone terminus and north Kent was opened in September 2003, with a second section, through to the St Pancras terminus, opening in November 2007. The total journey time was cut by only some 40 minutes, but the removal of the need to accommodate commuter trains increased the capacity of the route for the services through the Channel tunnel. The financial case was not strong, but its completion provided a complete high-speed link between London and continental European capitals.

A second high-speed line was also proposed, to link London with cities to the north. The planned Y-shaped network (London to Birmingham, with onward branches to Manchester and Leeds) was confirmed by the Conservative-Liberal coalition government at the end of 2010. After more reviews and delays, formal approval for construction to proceed was given in April 2020.

Since then, projected costs have continued to rise, completion times have been put back, and billions have been spent on tunnelling and compulsory purchases of land, only for the Infrastructure Projects Authority to conclude in July 2023 that the first two phases of the project appeared to be unachievable. This culminated in Prime Minister Rishi Sunak's announcement in October 2023 that only phase 1 of the project would go ahead, linking London and Birmingham, but with no guarantee that the London terminus would be at Euston rather than Old Oak Common, far from the city centre.

So, how could we have reached this sorry state of affairs? Was HS2 ever viable, or was it doomed by the inevitable extended timescales and problems related to building major infrastructure in a crowded island? The first thing to note is that extra capacity has long been needed, to ease overcrowding on the west coast main line. However, it need not have been a new high-speed line, particularly in view of the constraints involved: gently curving lines and stations sited relatively far apart.

The European country that has the largest and arguably most successful high-speed network is France, where TGV lines linking much of the country have been in place for decades. But France is much larger than the UK, and has lower population density, allowing track to be laid in long straight stretches with relatively little disruption to communities. Germany has its own network of high-speed ICE trains, but geographical constraints mean that tracks cannot be as straight, and the speed achieved is therefore limited in many places (and it is clear that the once admirable Deutsche Bahn network has become rather unreliable in recent years, doubtless adding to the difficulties).

The European country with perhaps the best and most highly integrated public transport network is Switzerland. However, it has no high-speed trains, simply because the size and topography of the country makes them unviable. Swiss trains are not fast, but they are very reliable and the preferred option for many journeys. The challenges for the UK are, in many ways, closer to those faced by Switzerland than France, in terms of its capacity for transport infrastructure. Although there are some long journeys to be made, for example to Scotland or the West Country, there is insufficient demand to justify dedicated high-speed links. Instead, most rail journeys take place in the area from the South East up to the Manchester or Leeds areas, and here the population density makes track construction problematic.

The journey times between London and Birmingham would be reduced by only about ten minutes by HS2, although savings on the (now cancelled) northern legs would have been more significant. However, the benefit-cost ratio is modest at best and, given the escalating cost, the project is difficult to justify in purely economic terms. Indeed, part of the economic argument was that shorter journey times would increase productivity. In these days where everyone can be in constant contact via mobile devices, this is a very weak argument.

Assumptions about passenger numbers are also likely to be very much on the optimistic side. UK trains are already expensive relative to services in other European countries, and flying from London to Manchester, for example, can be significantly cheaper than taking the train. Undoubtedly, high-speed travel would be sold at a premium and, whereas journeys booked well in advance and off-peak may be well used by the general public, peak-time trips are likely to be the preserve of business travellers. HS2 may never carry the number of passengers it was designed for.

The cost of the track per mile is many times higher than for a similar project in France, for example, because so much tunnelling is required to allow the track to be sufficiently straight while minimising disruption to communities and landscapes. And much of the cost inflation appears to have been deliberately hidden until Parliamentary approval had been given, according to a recent investigation by the *Sunday Times*.[¶]

It seems that projects such as HS2 acquire a life of their own, with those directly involved pushing ahead, either ignorant of the problems or, in some cases, knowingly ignoring them. Cheerleaders for the project talk of the money and time invested so far (the classic sunk cost fallacy), the need to complete all phases to reap the full benefits (which, in this case, is largely true), and the loss of prestige associated with cancellation. Indeed, it often seems that this last factor can be the most important in terms of decision making. HS2 was always envisaged as a 'world-leading' infrastructure project, with faster trains than those in other countries. It was gold-plated in all respects, rather than simply planned as an additional rail route linking major cities, to give the best possible benefit-cost ratio.

This makes the decision made by the government in October 2023 to build only Phase 1 of HS2, linking London and Birmingham, a particularly brave one. It has predictably been widely criticised. Admittedly, this line, if left without

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[¶] HS2: The secret files that expose a multibillion pound cover-up; *The Sunday Times,* 22 October 2023. https://www.thetimes.co.uk/article/hs2-billion-pound-coverup-cost-files-investigation-skzv2nxwj.

further high-speed connections, will look like a white elephant, but that is certainly better than creating a much larger and more expensive one. If the money saved from later stages is used in projects to improve east-west transport links between northern cities and to provide additional (normal speed) train capacity from Birmingham onwards, then future generations should be grateful.

HS2 has distinct parallels with Concorde: a prestige project pushed ahead while the rest of the world got cold feet about viability. The main difference is that the UK in the present case has no binding treaty obligations to effectively force it to pursue a project that it knew was deeply flawed.

Energy generation and storage

In tomorrow's planned Net Zero world, societies will rely on electricity to power everything: heating, cooling, lighting, cooking, transport and industrial production. This means a large increase in the amount of electricity generated, and it also means that essentially all of it should be zero carbon. In an ideal world, the market would be incentivised to find the most economic and reliable way to achieve this. In the real world, most developed countries are effectively betting the house on renewable energy.

The European Union, back in the days when the UK was a member, set the 20-20-20 targets as a major part of its climate change mitigation strategy. With a baseline of 1990, the targets set for 2020 were for a 20% reduction in greenhouse gas emissions, a 20% increase in the share of renewable energy and a 20% increase in energy efficiency. Clearly, there had to be a goal of greenhouse gas emissions reduction, since this is the key aim of the entire policy. Also, increasing energy efficiency is an entirely sensible thing to do if it can be done at an economic capital cost; simply consuming less energy benefits everyone. However, the renewable energy target was a clear example of picking winners. Since these targets were met (but not by all EU countries), the EU27 and UK have doubled down on longer-term goals, aiming to achieve Net Zero (no net emissions of greenhouse gas at all) by 2050. Not only that, but renewable energy is seen as the primary enabler.

This stance is seen by its cheerleaders as setting an example for the rest of the world to follow because, don't forget, it is *global* emissions that matter and everything that Europeans do to achieve Net Zero will count for nothing in the absence of real progress in emissions reduction from China, India, the United States and others. In reality, the UK and EU are demonstrating to the rest of the world how *not* to slash emissions sensibly. If we wanted to set an example for others to follow, we would be encouraging innovative projects designed to allow competing approaches to find the most efficient and cost-effective way to meet the target and then export the best technologies to allow others to do the same.

There are various types of renewable energy. Primarily, the energy received by our planet comes from the Sun. It is this solar energy, received over millions of years and locked away in the form of oil and gas, that has fuelled the vast expansion of the world's population and allowed the enormous economic progress made by the developed world. Solar, wind and wave energy are much more diffuse and require vastly more infrastructure to extract and utilise them. Conventional hydro and tidal energy are more concentrated and largely reliable sources, but each generation site is unique and there are no economies of scale. In fact, there is probably relatively little high-quality hydroelectricity generation capacity that remains untapped, and the dearth of tidal power stations surely teaches its own lesson.

The enthusiasm for renewables has resulted in the absurd situation where large-scale use of wood chips to generate electricity is encouraged, even though the carbon dioxide emissions per unit of electricity are higher even than for coal. This is justified by the argument that new trees can be planted and that these, over decades, will recapture the emitted CO_2. Since climate change lobbyists insist that emissions must peak and start to decline very soon, the logic behind this policy seems flawed, to put it mildly.

Wind energy has, of course, been tapped on a small scale for many centuries. Modern wind turbines merely represent a refinement and upscaling of windmills. Vast offshore wind farms are clearly a major technological achievement,

but they inevitably suffer from variable output (power output follows a cube law: for a doubling of wind speed, power output increases eight-fold). However, a greater drawback is the intermittency; there are times, particularly under a stationary high-pressure system, when there is insufficient wind for the turbines to work. This lack of output may last for days. Feeding variable amounts of electricity into the grid while keeping the system stable is a challenge; ensuring continuity of supply when there is no wind is much harder.

PV cells have become much more efficient over the last twenty years, and prices have come down significantly. However, they still suffer from the problem of intermittency, albeit in a more predictable way. Tidal power is even more predictable, but still intermittent to a degree, and no viable wave-powered generating system has yet been developed. Large-scale hydroelectric stations offer dispatchable capacity (they can be used at any time), but only while the reservoir of water remains sufficiently full.

The variability and intermittency of renewables is a manageable issue when their contribution to the total system is relatively low, but becomes harder to manage effectively as the installed capacity increases. This is why it is disingenuous of renewables supporters to talk about how low the cost of the generated electricity is. More important is the overall cost of providing a secure and stable electricity supply and this increases as renewables become more dominant.

Renewables are subsidised via a complex series of instruments. They are clearly not economically competitive with fossil fuels, even when these are loaded with the nominal cost of carbon dioxide emissions. This makes electricity costs in the UK and the rest of Europe considerably higher than in much of the rest of the world (including the USA, largely using domestically produced gas and oil). Not only is general manufacturing less competitive (heavy industry was largely transferred to the Far East as European costs became uncompetitive, for example), but nearly all PV panels and wind turbines are made overseas, largely in China, even if the companies selling and installing them are European.

Our reliance on China does not end there, since it dominates supply of the key materials needed for wind turbines, such as cobalt and rare earth metals. European countries are locked into highly ambitious targets to slash emissions of greenhouse gas that cost taxpayers and consumers considerable sums. These in turn largely benefit utilities companies and overseas manufacturers. Part of China's continued increase in annual CO_2 emissions comes from the manufacture of solar panels and wind turbine components used to reduce European domestic greenhouse gas emissions. As Napoleon said, 'never interrupt your enemy when he is making a mistake.'

Politicians across the board have been persuaded that renewables are 'good' and that they should provide the largest part of our energy needs, hence the setting of targets and introduction of subsidies to allow them to compete in the electricity generating market. Renewables may indeed be the winner to pick, but only if an economic way of storing enormous amounts of energy can be developed, so as to maintain a stable, reliable and affordable supply of the energy vital for a modern society. Unfortunately, we are not remotely close to achieving this.

Policymakers have an unfortunate habit of prescribing specific solutions to elements of a problem, rather than trying to address higher-level goals in the most efficient way. In the case of the climate change mitigation effort, the goal is a drastic reduction in net greenhouse gas emissions *worldwide*. The EU and UK have chosen to lead the charge to encourage the rest of the world to follow (of which there is little sign at present). In a rational world, the focus would be on the global goal. The climate change industry would say this is what is being done, by agreeing targets at the vast annual COP (Conference of the Parties to the UN Framework Convention on Climate Change). But fine-sounding declarations are meaningless without the technology to achieve them.

Since pretty much all the energy we use (other than from nuclear fission) is derived ultimately from the Sun, it makes sense to tap this directly if it can be done efficiently. Nevertheless, however efficient photovoltaic cells may become there remains the intermittency issue. There are suggestions that they might be deployed in large arrays in space, where they could be oriented towards the Sun and provide constant energy. Apart from the cost and complexity of the deployment, the key issue is how to get the energy down to the

Earth's surface safely and securely. Microwave transmission has been suggested, but there are a number of obvious difficulties in managing this safely. The approach is unlikely to be utilisable in the near future, but that does not mean it might not be contributing in a generation or two's time.

The developed world has picked wind and solar power, while largely ignoring the potential of the one proven, reliable, zero-carbon source of electricity, nuclear fission (considered, irrationally, as insufficiently green). No amount of renewable energy capacity can guarantee a secure and uninterrupted supply of electricity without either vast energy storage capacity (not available) or reliable, dispatchable backup capacity.

Nuclear generating capacity is expensive to build, not least because of the cost of the safety systems required to reduce the chances of accidental release of radioactive material to as close to zero as possible. This is because of the belief in the early days of nuclear fission development (for both peaceful and military use) that there was no safe exposure level for radiation. Evidence that this is not the case and that low doses of radiation can in fact be harmless, or even beneficial for health (hormesis) has been available for many years,[**] but authorities have been unwilling to set more realistic exposure criteria in view of the likelihood of a public backlash. Almost certainly, this is largely because of the existence of nuclear weapons; to many people, the word 'nuclear' will always have negative connotations.

Nevertheless, France is an example (unfortunately the only one) of a country that decided to rely on nuclear fission for the bulk of its domestic electricity in the early days of commercialisation. This has given it safe, secure and inexpensive baseload. Unfortunately, this is in the process of being reduced by a move towards more renewables. Other countries (including the UK) have begun to build new nuclear capacity to replace older reactors, but these have been beset by delays and cost overruns. Rather belatedly, more encouragement is being given to the development of small modular reactors (SMRs), which can be built in factories and installed where needed.

Nuclear fission is not necessarily the complete answer, even if costs can be reduced, because it cannot be ramped up and down easily (although for some newer designs this is becoming less of an issue) and needs to generate continuously to be economic. Further reliable dispatchable capacity is needed to maintain grid security, and the best solution currently available is the gas turbine. Until better solutions are available, gas will remain an essential part of our generating capacity.

Another important issue regarding energy systems, over and above the overall cost and the need to maintain security of supply at all times, is the concept of energy return on energy invested (EROEI). Put simply, sophisticated modern economies were unable to develop until coal replaced wood as the primary source of energy during the Industrial Revolution. The energy needed to mine coal, relative to the energy produced by burning them, was far less, and the vast increase in energy availability literally fuelled the rapid economic development of industrialised societies.

Weissbach et al. compare a range of energy generation technologies on the basis of EROEI (actually the EMROI, or 'energy money returned on invested', often used interchangeably with EROEI). This shows that solar PV, biomass (and wind, allowing for buffering to cover intermittency) fall below the economic threshold for energy generation, with the best performers in contrast being nuclear, combined cycle gas turbines and hydro (although this of course has geographical constraints). These findings are summarised in Figure 1. The unbuffered figures are

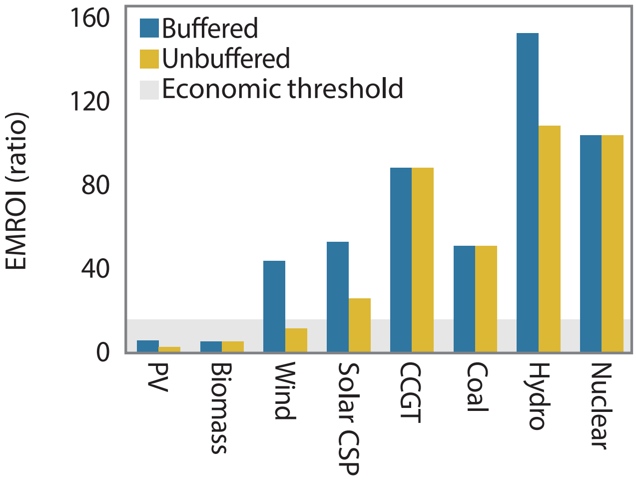

Figure 1: EMROI of generation technologies

PV for Germany, biomass for corn, CSP for desert, medium sized hydro, PWR nuclear.

[**] E Calabrese and M Paunio. *A-Bombs, Bears and Corrupted Science*. https://www.netzerowatch.com/all-papers/a-bombs-bears-and-corrupted-science.

based solely on energy input and output, whereas the buffered figures take account of the need to provide energy storage to smooth the output of intermittent sources (solar, wind and hydro).

The arguments for a better thought-out, integrated electricity generating system are covered in more detail by the former Chief Scientist to the Department of the Environment, David MacKay.[††] Unfortunately, the lessons he taught do not seem to be learnt, and politicians of all stripes continue to back renewable energy despite the obvious drawbacks of the available technologies.

Carbon capture and storage

Net Zero does not mean that no carbon dioxide can be emitted. Policymakers intend that some of it should instead be captured from the atmosphere and locked away, effectively permanently, to help lower the level of CO_2 in the air (so-called carbon capture and storage; CCS). Carbon dioxide can be captured, for example, by passing flue gases from a coal- or gas-fired power station or cement works through a tank of monoethanolamine (or other amine). This binds the gas, which can then be released by heating the amine, which in turn can be reused.

This is the type of carbon capture currently being used, and it is regarded as a tool to be deployed more widely as a significant part of the drive to achieve Net Zero. However, more broadly, CO_2 can be captured from the air, where it is present at very low levels. Various approaches have been proposed, most involving a large surface area capable of absorbing carbon dioxide selectively from the atmosphere. In the longer term, new technologies to achieve this end have great potential to reduce atmospheric CO_2 levels, since they could be deployed anywhere and need not be associated with large-scale sources of the gas.

However, capturing CO_2 is the simple part; locking it away, essentially permanently, is much harder. The approach being followed is to inject the gas into underground reservoirs, a technique proven in the oil and gas industry, where injection of CO_2 under pressure is used to increase recovery of fossil fuels (which some readers may find somewhat ironic). The problem is that each project is unique, so there are no economies of scale that might make rollout cost-effective.

Governments past and present have offered funding for demonstration projects, but there has been precious little success. In many cases, companies have abandoned projects when it became clear that they were not viable. As well as being relatively capital intensive, CCS requires significant energy inputs to capture, release, (sometimes) compress, transport and inject the gas into a reservoir. Of course, CO_2 does not necessarily need to be injected into an underground reservoir. It could, for example, be chemically combined with existing minerals to create new, stable carbonate rock, or used as a feedstock for other chemical production. The UK government therefore refers to carbon capture, usage and storage (CCUS).

The most recent update on the government's strategy was in February 2019,[‡‡] giving a clear sense that this is not something for which big results are expected in the near future. To quote:

> CCUS has the potential to decarbonise the economy and maximise economic opportunities for the UK. However, it is currently expensive and cost reductions are necessary to be able to deploy CCUS cost effectively in the UK, providing value for money for both the taxpayer and consumers.
>
> The government has set out a programme of work that will be undertaken to establish the additional steps that are required to meet the ambition of having the option to deploy CCUS at scale during the 2030s, subject to cost reduction. In delivering this work, government will work collaboratively with the CCUS industry, including existing projects.

Don't hold your breath, then. And yet there is a clear understanding that Net Zero will be virtually impossible to achieve without a significant contribution from CCUS, since this would allow high-emission but indispensable industries such as cement to operate. The International Energy Agency published a report on CCUS in September

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[††] *Sustainable Energy, Without the Hot Air*; David MacKay; 2009; https://www.withouthotair.com/.

[‡‡] https://www.gov.uk/guidance/uk-carbon-capture-and-storage-government-funding-and-support.

2020,[§§] at a time when the global goal of Net Zero was planned to be met in 2070. This already required a large contribution from CCUS but, to quote the report:

> CCUS accounts for nearly 15% of the cumulative reduction in emissions in the Sustainable Development Scenario. Moving the net-zero goalposts from 2070 to 2050 would require almost 50% more CCUS deployment.

To be fair, various approaches to this problem are being pursued, including using captured CO_2 as a feedstock for biofuels, but there is an assumption that somehow a set of currently uneconomic and unscalable technologies will, over the next 25 years, be widely used to reduce carbon dioxide emissions. This is more than simply picking a winner; it is surely pie in the sky to imagine that this could happen without at least the imposition of swingeing carbon taxes. It is extremely doubtful that citizens of democratic societies would be willing for that to happen, and it's certain that autocracies would not willingly impoverish their populations to do so.

Heat pumps

When we talk about reaching Net Zero, the focus has often been on the electricity generation sector. Granted, this will become more important as electricity is increasingly used to replace gas and oil in other sectors, but the electricity grid in the UK is now a far lower emitter of greenhouse gas than a few decades ago. One of the more difficult sectors to decarbonise, on the other hand, is domestic (and commercial) heating and cooling. Air conditioning is only used to a small extent in this country at present (although that may change), but heating is a necessity. The majority of modern houses use a gas boiler and radiators, while oil-fired boilers are used by many people outside urban areas.

Replacing these is not easy. The two main proposed alternatives are hydrogen boilers and heat pumps. Burning hydrogen is no great problem: coal gas (or town gas), used in the UK until the 1960s transition to natural gas, was composed of hydrogen and carbon monoxide. Boiler manufacturers are confident that hydrogen-compatible boilers could be available in a few years. The bigger problems are that the hydrogen has to be from a low-carbon source (increasing the cost considerably), and that, as the lightest element, it is much more prone to leak from joints or flaws in pipework.

For whatever reason, policymakers have decided that retrofitting heat pumps is the way forward. In the great majority of cases, this means using air-source pumps, since it is not usually practical to dig up gardens to accommodate the more efficient ground-source models. Heat pumps are often described as fridges in reverse and they are, in fact, rather efficient. They require a supply of electricity, but produce up to three or four times the energy input, meaning the energy used to heat a house could be only 20–25% of that from a conventional boiler. So far, so good, but the price of electricity is currently around four times that of gas in terms of energy output, so the actual operating cost may not be reduced very much.[¶¶]

Another problem with heat pumps is that the maximum temperature they can heat water to is significantly lower. Domestic radiators normally run with water at 60°C or higher, but an air source heat pump is likely to heat water to 40–50°C. This means that larger radiators or underfloor heating are required. Additional insulation is almost certainly needed too. Anecdotal evidence suggests that consumer satisfaction with heat pumps is quite mixed. What is for sure is that the initial cost of the pump – around £4–8,000 after a £7,500 taxpayer subsidy – is not the whole story. It is likely that at least an equivalent sum would be needed to change radiators and improve insulation.

Heat pumps are not a cheap option and have limitations. They are also not suitable for use across the complete range of housing. Older, single-brick wall houses may be too expensive to insulate to the extent necessary, and some high-density housing may not have enough space to

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[§§] https://www.iea.org/reports/ccus-in-clean-energy-transitions.

[¶¶] Montford A; Heat pumps: Mythology and Actuality; GWPF, July 2023; https://www.thegwpf.org/publications/new-paper-reveals-governments-heat-pump-plan-as-uneconomic/.

allow heat pumps to be installed sufficiently far from neighbouring properties; they need to be at least a metre from the boundary and also produce no more than 42dB of noise at this point (the unit itself can be as noisy as 60 dB). It is difficult to meet these standards in blocks of apartments although, in some urban areas, district heating may be in use.

The other potential replacements for gas or oil burners are electric heaters. Since electricity is several times more expensive than gas, it is normally quite uneconomic to rely on this mode of heating. The answer to this in the relatively recent past was the night storage heater, using cheaper off-peak electricity to heat a thermal block that then released its heat during the following day. Although popular at one time, they suffer from lack of controllability and lag time: they cannot provide heat reliably when it is needed.

There are of course plenty of electric heaters – mainly oil-filled radiators and convector heaters – in frequent use to provide top-up heat in the short term or to heat individual rooms. However, more extensive use is really only economic in very well insulated housing. Many flats, where warmth may be retained well because of surrounding units, can be suitable, for example, and newly-built houses should have far better insulation than those built a few decades ago. Some new homes are built to Passivehaus standards (at a premium), which means that very little if any heating is needed. However, this leaves a very large number of perfectly satisfactory houses that would be extremely costly to bring up to modern standards of insulation. In the case of listed dwellings, this would not even be allowed.

Although homeowners have been encouraged to improve the insulation of their houses, the primary focus of government policy is currently to incentivise consumers to install air-source heat pumps, which in nearly all cases will need considerable extra expense in insulation and new radiators. A recent research briefing for parliamentarians gives a rather negative impression of both the current situation and future prospects.[***] To quote:

> Heat pumps are widely used in some European countries but are currently installed in 1% of UK homes. The Climate Change Committee projects that, to reach Net Zero, domestic heat pumps will be needed in at least half, but likely closer to 80%, of homes by 2050…The UK Government has a target of 600,000 installations per year by 2028 and 72,000 were installed in 2022…Heat pump installation costs are higher than gas boilers, in part due to the need for additional retrofitting…Heat pumps currently have similar running costs to gas boilers…The public's interest in and understanding of heat pumps is low.

On the face of it, the UK is a laggard in Europe in the adoption of heat pumps. For example, more than ten times the number of heat pumps are installed annually in France compared with the UK. However, this is somewhat misleading, since most of the units in France are installed primarily for cooling rather than heating.[†††] However, there are other reasons for the difference. One is the relative cost of electricity and gas. Research by Nesta[‡‡‡] has shown that a ratio of a little over 3:1 for electricity and gas prices means that heat pump running costs are the same as those of gas heating. However, the ratio in the UK averaged 3.8 from 2011 to 2021 and has been significantly higher since. So, as part of the drive towards Net Zero, consumers are being encouraged to spend thousands of pounds to replace a perfectly satisfactory heating system with something likely to cost them a similar amount to run. Germany, Belgium and the UK have the highest electricity/gas price ratios in Europe and rather small numbers of heat pumps.

The other important factor is the existence of an extensive gas grid. In Scandinavia, where heat pumps have been widely used for some time, there is little competition from gas, since gas grids are very limited or non-existent. Gas grids also give the option of piping hydrogen as a replacement for methane, which could prove to be a better solution for many than installing a heat pump (if the cost of generating green hydrogen can be reduced sufficiently).

Overall, we can see that there is no one-size-fits-all solution to the transition to low-carbon heating. Circumstances vary between countries

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[***] POSTnote research briefing; Heat pumps, 14.07.23; https://post.parliament.uk/research-briefings/post-pn-0699/.

[†††] From powerhouses to latecomers: how different European countries are adopting heat pumps; Nesta; 08 August 2023.

[‡‡‡] How the energy crisis affects the case for heat pumps; Nesta; 25 October 2022.

and governments would be better advised to encourage a competitive environment in which consumers are able to choose the solution that suits them best. Market forces and economics will do the rest.

Electric vehicles

The other major energy-consuming sector of the economy due for decarbonisation is transport. Currently, the only viable solution for flying is the development of synthetic fuels, so the focus is primarily on road transport. The internal combustion engine (ICE) – whether diesel- or petrol-driven – is a highly efficient machine developed over many decades. The current generation (meeting the Euro 6 emission standard) is both highly fuel-efficient (50–60 mpg for the careful driver) and powerful, giving family cars the performance of sports cars of fifty years ago.

Some campaigners would like to see motorised personal transport use decline significantly, to be replaced by buses, trains, bikes and pedestrians. In urban areas, many people do not need to use cars, but for rural dwellers they remain essential and for many others the sheer convenience of the car means they would not willingly part with them. Even in Switzerland and the Netherlands, both boasting highly efficient, reliable and integrated public transport networks, traffic jams are a fact of life in some areas. The UK government has decided that the ICE must be phased out, to be replaced by electric vehicles. In their initial enthusiasm, they set a date of 2030 as the cut off point for the sale of new conventionally-powered cars (including hybrids). This has more recently (2023) been extended to 2035, in line with the rest of Europe.

Nevertheless, car manufacturers will have to meet rising targets for the number of BEVs sold each year, reaching 80% by 2030. If these targets are not met, there is to be a penalty of £15,000 per vehicle. Unfortunately (for the government and the car industry) the signs are not good that there will be sufficient consumer demand for BEV given the current price premiums and concerns about the adequacy of the charging infrastructure. This particular 'winner' looks likely to cause significant headaches over coming years.

The main alternatives to use of BEVs are to continue to use ICEVs, but fuelling them from low or zero-carbon sources: biofuels, synthetic fuels, or hydrogen. The first of these approaches has been approved by the German government following lobbying by manufacturers. This allows continued indefinite sale of ICEVs that can be powered by synthetic fuels, and was seen as essential for the continued production of high-performance sports cars. Currently, it is expected that the cost of synthetic fuels would be too high for most drivers to find acceptable. Nevertheless, there will be large numbers of petrol and diesel cars on the road even after 2035 and it is possible that synthetic fuels could be developed that will be competitive with conventional ones.

Hydrogen has long been touted as a fuel to replace petrol and diesel, and there are hydrogen-powered vehicles in successful operation. Fuel cells are considered by many to be the best way to use the hydrogen; in the cells, hydrogen and oxygen are combined to generate electricity, used to power the same sort of motors found in BEVs. The exhaust is pure water. However, hydrogen can also be used to power internal combustion engines with relatively little modification. JCB and other manufacturers of heavy equipment and lorries are following this development path. Batteries cannot keep the machines running for a working day, but hydrogen can.

Both electric and hydrogen-powered vehicles have their disadvantages, but the political consensus around much of the Western world has been that battery power is the future. However, BEVs are more expensive to make, despite real improvements in battery technology in recent years and cannot (yet) match the range of most conventionally powered cars. Not only that, but recharging the batteries takes much longer than refuelling with petrol or diesel and, as importantly, the network of public chargers is growing far too slowly to give the increasing numbers of BEVs on the road good access when needed.

Battery packs are not only the most expensive component of the car, they are also very heavy, leading to greater wear of road surfaces (and tyres) and, in the longer run, being a potential headache for operators of existing multi-storey car parks. Also, current batteries require lithium, cobalt and other relatively uncommon elements in their manufacture. While new deposits will undoubtedly be found and exploited, there are doubts that extraction rates are high enough to supply the needs of the car industry if policy targets are to be met.

Although BEVs produce no CO_2 emissions in use (given that they are charged with 'zero-carbon' electricity, which is not currently the case) their manufacture is highly carbon-intensive and their green credentials over a full life-cycle compared to an efficient modern ICEV are not as black and white as many people may think. To compound this, Chinese companies are taking an increasing share of both battery manufacture and car sales, largely by undercutting European, US and Japanese car makers.

In contrast to BEVs, hydrogen-powered vehicles remain effectively at the prototype stage. There are some on the road and their mass production is perfectly feasible, but there is essentially no infrastructure for refuelling. Producing, storing and transporting hydrogen indeed presents real problems. To make its use as part of a drive towards Net Zero worthwhile, it must be produced from a zero-carbon source. The most likely way is electrolysis of water, but this is energy intensive and, of course, itself requires electricity. More energy is consumed in its distribution, and using it to power a car is not 100% efficient.

This makes hydrogen a far less efficient use of energy than powering cars directly with electricity stored in batteries. However, this electricity has to be generated somewhere and transmitted – with losses – to the recharging point. In terms of overall energy used, the most efficient way to power vehicles is still to burn petrol or diesel in an internal combustion engine. 'Green' hydrogen only really becomes viable with the availability of a supply of low-cost, zero-carbon electricity. This in principle could be from wind turbines or photovoltaic cells, where output greater than needed by the electricity grid is essentially worthless. However, this is not an argument for installing even more renewable energy generating capacity, which will only serve to push up overall energy prices.

Moreover, hydrogen is the lightest element and difficult to handle. It has to be compressed to be stored and its low molecular weight makes it extremely prone to leakage. This makes it particularly difficult to distribute via pipelines. Creating a refuelling network could therefore be problematic, although for the car owners, the process itself would be much quicker than recharging batteries, meaning that far fewer refuelling points would be needed than recharging points. Hydrogen-powered cars would also be far more flexible than BEVs.

The most recent figures from the Society of Motor Manufacturers and Traders showed that although sales of electrified cars continued to grow, growth was stronger for hybrids than for battery electric vehicles (BEVs)[§§§]. The BEV market share had, by October 2023, grown to 15.6%, a modest rise from the 14.8% for 2022. Fewer than one in four of the new registrations were for a private vehicle, with the fleet market taking the majority. The sales targets from 2024 onwards look rather ambitious.

The motor car became the preferred form of transport because consumers saw the benefits. Networks of petrol stations developed on the basis of need. Market forces drove this development, with no incentivisation or planning by government. Changes in preferred vehicle and engine type were driven by consumer preferences, influenced to some extent by road tax levels. What the UK and other governments are trying to achieve now is an unprecedented change in types of vehicle, driven by top-down backing of a single technology, with little thought for consumer needs, nor for their ability to pay.

Summary and conclusions

As a general rule, setting specific targets and trying to meet them by subsidising the application of chosen technologies is not a good idea. The examples covered in this study illustrate the

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[§§§] October new car market beats pre-pandemic levels but subdued BEV growth hinders green goals; SMMT; 6 November 2023. https://www.smmt.co.uk/2023/11/october-new-car-market-beats-pre-pandemic-levels-but-subdued-ev-growth-hinders-green-goals/

difference between promoting what happens to be available and developing what actually works, both technically and economically. Two of the case studies – Concorde and HS2 – were/are essentially projects championed to quite a significant degree in the name of national prestige. This can never be a good reason to pursue a plan.

LEDs became the preferred choice of consumers to replace tungsten filament bulbs, despite governments subsidising the rollout of the unpopular CFLs. And, in an area where no policy targets were ever set, mobile phones emerged and transformed society purely because private companies developed what consumers never realised they wanted but proved most willing to pay for.

The push to reach Net Zero in the UK and across Europe by 2050 also has a large element of national prestige. The EU took what they considered to be the moral high ground by setting the first targets, and the UK became the first country to make them legally binding (closely followed by others). Enthusiasts believe they are showing the rest of the world the way, and that the Paris Climate Accord will bring about the drastic reduction in carbon dioxide emissions the Intergovernmental Panel on Climate Change tells us is necessary. The naïve assumption is that the rest of the world, including China and India, will follow in our trailblazing footsteps. More likely they will learn from our expensive mistakes.

Although great progress has been made both with domestic greenhouse gas emissions (now the lowest since Victorian times in the UK), in terms of per capita emissions and the carbon intensity of the economy, pushing ahead with the remaining plan will show the rest of the world only how to achieve Net Zero while severely damaging the economy, and most likely causing a degree of social breakdown. In the meantime, the main beneficiary is China, now building much of the equipment used for renewable energy infrastructure in Europe and in the process of becoming pre-eminent in the manufacture of lithium batteries and electric vehicles.

The way to achieve *global* Net Zero, the only target that means anything, is to develop new and improved ways to decarbonise sectors of the economy in ways that consumers accept and that do not require ongoing taxpayer subsidy. If we can harness our proven scientific and engineering ingenuity to develop low-carbon technologies that consumers prefer, we have a chance to benefit economically while also benefitting others around the world.

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People are naturally concerned about the environment, and want to see policies that protect it, while enhancing human wellbeing; policies that don't hurt, but help.

The Global Warming Policy Foundation (GWPF) is committed to the search for practical policies. Our aim is to raise standards in learning and understanding through rigorous research and analysis, to help inform a balanced debate amongst the interested public and decision-makers. We aim to create an educational platform on which common ground can be established, helping to overcome polarisation and partisanship. We aim to promote a culture of debate, respect, and a hunger for knowledge.

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