Picking Winners

Learning the lessons of history: why technology transitions are best left to market forces

Summary

Nearly all successfully commercialised new technologies have achieved their 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 see is the best available technology to achieve a particular policy goal and back it to the exclusion of others. But picking winners is seldom successful.

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

- Concorde
- The replacement of filament lamps by LEDs
- Mobile phones
- Covid vaccine development
- 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 also reviews the following areas:

- 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, involving the use of taxpayers' money to drive consumer acceptance of technologies currently incapable of fully meeting the targets in an economic way. 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.

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1. 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 a competitive market that lets innovation proceed as well as providing stable supplies of established goods. In this environment, new technologies can and do get commercialised, allowing consumers to determine their market success. New technologies take over because they offer advantages to consumers; in the words of Sheik 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. The 2008 Climate Change Act obliged the government to reduce emissions of greenhouse gases by 80% over the 1990 baseline by 2050, more recently revised to make the target 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. Neither does it 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 is deemed to be the best available.

Thus, faith is being placed in solar and wind energy to supply the bulk of our energy needs, 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 turned out to be losers. This paper offers some lessons from recent history plus a review of the 'winning' technologies backed to achieve Net Zero. It is to be hoped that future governments will learn from these lessons rather than continue to repeat them.

2. 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

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Sputnik 1. After the devastation of the Second World War, economic growth was strong, oil prices were low (about $3 a barrel through the 1960s, an almost inconceivable 30 cents in today's money) and most people were unquestioning about the benefits technology could bring. Against this background, development of a supersonic airliner must have seemed like 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 in English version of the spelling should be Concord. In June that same year, PanAm signed sales options for six planes and President Kennedy announced backing for a US 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 '60s was quite rapid. Work on the airframe started in September 1965 and prototype construction began the following year. By May '67, 16 airlines had agreed 74 sales options and in December 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 airline. 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 '71. The following year, 16 production aircraft were authorised; BOAC ordered 5 and Air France 4, 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. 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 400% 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 may have decided to cut their losses and abandon the project. However, in July 1975 Prime Minister Harold Wilson and President Valerie Giscard d'Estaing agreed to continue with Concorde but to limit production to 16 planes. It is worthwhile looking further into this, particularly as Wilson as incoming PM 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.[1] It appeared that the political and technological aspects of the cooperation outweighed the economics.

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

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The UK aeronautic 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 (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. [2]]

So, the UK government found itself effectively trapped in a situation where it was committed to the continued funding of a project whose economics were at best doubtful, at a time when it was struggling to cut expenditure. But for some, prestige and politics overshadowed mere economics. In May 1974, when the Labour government was agonising about the project, and a year before the agreement to continue but to build only 16 planes, Tony Benn (then secretary of state for industry) presented a supportive paper to the cabinet[3]. 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."

Against this background, the project went on in a limited way and 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 boom associated with travelling at this speed. 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.

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 in the process of being repeated in the case of HS2 (see below).

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[2] The Road to Concorde: Franco-British Relations and the Supersonic Project; Lewis Johnman, Frances M B Lynch; Contemporary European History; Vol 11, No 2 (May 2002); pp229-252; https://www.jstor.org/stable/20081830

[3] 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

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3. Domestic lighting

In 1879, 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 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, the development of fluorescent tubes in the 1930s gave an alternative to filament lamps that were about three times as efficient and suitable for indoor use. By the 1950s, they were very widely used for lighting commercial premises and also for some domestic use, largely kitchens and garages. Their physical size and inflexibility, plus the rather harsh light quality and inherent flicker made them unsuitable for most in-home lighting.

In order to make fluorescent lighting more flexible for general use, Compact Fluorescent Lamps (CFLs) were developed. The UK,(still an EU member state at the time), in December 2008 committed to a phase out of incandescent bulbs over a number of years, starting in September 2009. Essentially the only alternative at the time was the CFL, which suffered both from the quality of the light produced, as mentioned, but also from a significant time to reach full brightness. For this reason, many people took the option of stockpiling filament bulbs before their phase-out rather than move to CFLs. In 2010, a research briefing was produced by the House of Commons library summarising the situation and two other issues associated with this change: sensitivity of some people to the UV radiation from CFLs and also the potential risk from their mercury content. [4]

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, announced by Hilary Benn, then Secretary of State for Environment, Food and Rural Affairs. Two specific schemes were introduced to encourage the replacement of tungsten filament bulbs by low-energy alternatives: the Carbon Emissions Reduction Target (CERT) and the Community Energy Savings Programme (CESP).

CERT, which ran from April 2008 till December 2012 set the parameters for improving the energy efficiency of households to meet the commitments set under the Climate Change Act. CESP was a specific policy to improve energy efficiency in the most deprived areas of the country, running from October 2009 till December 2012. They in turn followed other government initiatives, including the Energy Efficiency Commitment (EEC) and Energy Company Obligation (ECO). Although having the same broad objectives, the details and specific objectives differed; a good illustration of the tendency of policymakers to over-complicate matters. 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 were subsidising sales to encourage take-up. Many householders will have some of these bulbs sitting at the back of a cupboard, having found 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, highly flexible LED technology. People have been willing to pay significantly higher

[4] The phasing out of incandescent light bulbs; SN/SC/4958; Louise Smith; 23 June 2010

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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, 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.

4. Mobile phones

The two areas we have looked at so far are classic examples of governments backing technologies that turned out to be failures in the market. Let's consider in contrast an area where successful development has been entirely a function of free market innovation. 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, followed by the UK, France and Germany during the following three years). These 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 that 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. This was effectively the start of the smart phone era, with the rapid development of competing iOS- and Android-based phones (and even Windows mobile for a time). Today, just thirty years since GSM phones first hit the market, smart phones are ubiquitous, providing full internet access, sophisticated cameras, voice recording and all the functionality of a desktop computer for a few hundred pounds and a few pounds a 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. They have played their part by making available parts of the wireless spectrum which providers can use. For each generation of technology, companies (or consortia) have bid for parts of the wireless spectrum as they have

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become available, largely to provide better and more widespread reception for users. The most recent auction in the UK for parts of the 700MHz and 3.6-3.8GHz 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.

5. Covid-19 vaccine development

In late 2019, reports began to emerge of a new respiratory virus causing pneumonia-like symptoms in Wuhan, the capital of the Chinese province of Hubei. This was only reported officially to local government at the end of December, but by 8 January 2020 the cause of the outbreak was identified as a new coronavirus, SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2). On 23 January, the UK government advised against all but essential travel to Wuhan, updated by 30 January to advice not to travel anywhere in mainland China. By then, British Airways had suspended all flights to and from China, but on the same date, the first two cases of Covid-19 were confirmed in the UK.

From a handful of cases in early February, the situation rapidly escalated in the UK and round the world. By the middle of March, 55 people had died of the virus, the Foreign Office advised against all unnecessary foreign travel , markets were in meltdown, panic buying was starting and society was beginning to shut down. By 26 March, the first lockdown came into force, all but essential shops were closed and people were only permitted to go out for shopping or for (limited) exercise (in fact, very many people had already begun to severely restrict their movements and contacts before they were obliged to do so). Restrictions were only loosened in late May and personal contacts were restricted to a ‘bubble’ of six individuals. The UK death toll was by this stage about 50,000. Covid testing had been rolled out rapidly, but the only way seen to reduce the spread of disease was by restricting personal contacts.

Fortunately, the search for effective vaccines was underway. In April 2020, soon after the first lockdown came into force, the government set up the Vaccine Task Force, bringing together scientists, civil servants and industry. On 16 May, Kate Bingham was appointed chairman. She was not an obvious choice for a governmental body, being a venture capitalist, but her breadth of knowledge and contacts proved crucial. By 27 October, an article by Bingham in the Lancet described how the task force had selected six candidate vaccines from an initial pool of 240. Clearly, these had not all been developed from scratch, but allocation of government funds to place large orders for the most promising potential vaccines allowed the companies involved to push ahead as fast as possible.

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The results were astounding. The UK was the first country to authorise a Covid-19 vaccine, this being the Pfizer-BioNTech version (mRNA-based, which first went into clinical trial in April), quickly followed by the University of Oxford/AstraZeneca one (a viral vector vaccine) and Moderna (also mRNA-based) vaccine. The first vaccination was given on 8 December and, by January 2021 a full-scale rollout of vaccination was in progress, targeting the most vulnerable first.

The other key factor that allowed vaccines to be made available rapidly rather than the more normal ten-year plus timescale was the shortening of the safety testing cycle. Because of the urgency of the issue, cutting corners was deemed to be acceptable although this was a contributory factor in the rise of the anti-vaxxers. Nevertheless, this was a salutary lesson in balancing risk against benefit.

We have already seen the importance of cutting through the normal bureaucracy and allowing a knowledgeable group of people to make informed decisions as quickly as possible. But this was in itself not sufficient. The fact was that governments (and charities, such as the Gates Foundation) were prepared to put forward large amounts of money to guarantee the best chance of success. There was no cost-benefit calculation made. In today's world it was deemed unacceptable not to minimise deaths at whatever cost (including, for example, the ongoing problems in the education sector arising from school and university closures). The alternative would have been something akin to the 1918 Spanish flu pandemic, in which it is estimated that up to 50 million people died worldwide.

The lesson is that, given the resources, almost any realistic technical goal can be rapidly achieved. Governments did not pick winners, but allowed competitive development of likely candidates by funding their manufacture up-front. This may be necessary in extremis, but is unaffordable in most cases.

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6. 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 many 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 the second section linking this via a series of tunnels to a newly-constructed terminus at St Pancras 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 high-speed trains. The financial case was not a strong one, but its completion did provide a 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 project had been championed by Lord Adonis among others and 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 purchase 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 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, outside of the centre.

So, how could we have reached this sorry state of affairs? Was HS2 ever viable, or was it perhaps doomed by the extended timescale and problems related to building major infrastructure in a crowded island? The first thing to note is that extra rail capacity has been needed for some time, to ease overcrowding on the west coast main line. However, this need not be a new high speed line. High speed rail has a number of constraints, in particular requiring curves to be very gently and having stations 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 a much larger country than the UK, with lower population density, allowing track to be laid in long straight stretches with relatively little disruption to communities. Germany has its own network of ICE trains, but geographical constraints mean that tracks cannot be as straight and the speed on German high speed trains 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 of running high speed trains).

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

Journey time between London and Birmingham would be reduced by only about ten minutes by this phase of HS2, although savings on the (now cancelled) northern legs would be more significant. However, the benefit-cost ratio is modest and 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. Already, UK train services are generally 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

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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, for the simple reason that 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[5].

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, simply 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, which has predictably been widely criticised. Admittedly, this line, if left without further high-speed connections, will look like a white elephant, but that is certainly better than creating a much larger and more expensive white elephant. 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 as a project has distinct parallels with Concorde: a prestige project pushed ahead by the UK and France while the rest of the world got cold feet about the viability of supersonic transport. The main difference is that the UK in the present case has no binding treaty obligations to effectively force it to pursue a project it has realised was deeply flawed from the outset.

7. Electricity generation and storage

In tomorrow's planned Net Zero world, societies will effectively 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 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

[5] HS2: The secret files that expose a multibillion pound cover-up; The Sunday Times, 22 October 2023

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energy and a 20% increase in energy efficiency. Clearly, there had to be a goal of GHG emissions reduction, since this is the key aim of the entire policy. Also, increasing energy efficiency is an entirely sensible thing to do; 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, with a policy aim of achieving Net Zero (ie, no net emissions of GHG at all) by 2050. Not only that, but renewable energy is seen as the primary tool to achieve this.

This occupation of the moral high ground 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, we are demonstrating to the rest of the world how *not* to slash emissions sensibly. If we wanted to set a worthwhile 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 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 which, 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 off-shore 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 the 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 be for days at a time. Feeding variable amounts of electricity into the grid while keeping it stable is a challenge; ensuring continuity of supply when there is no wind is much harder.

Photovoltaic cells have become much more efficient over the last twenty or so years, as the technology has developed, and prices have come down very 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

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been developed. Large-scale hydroelectric stations offer despatchable capacity (ie, 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 becomes higher 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 supply of the key materials needed for wind turbines (eg cobalt and rare earth metals) is dominated by them. European countries are locked into highly ambitious targets to slash emissions of GHG 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 GHG 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 various subsidies to allow them to compete in the electricity generating market. Renewables could indeed be the winner to pick, but only if an economic way of storing enormous amounts of energy could 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 GHG 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 conferences (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. However efficient photovoltaic cells may become there remains the intermittency issue. There are suggestions that they could 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

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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. This is not an approach likely to be utilisable in the near future, but that does not mean it might not be making a contribution in a generation or two's time.

The developed world has picked wind and solar power to underpin societies in the 21st Century, while largely ignoring the potential of the one proven, reliable, zero-carbon source of electricity, nuclear fission (considered 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, despatchable alternative generating 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 beneficial for health (hormesis) has been available for many years[6], 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 example) 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 the country a safe, secure and inexpensive base load capacity, unfortunately 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, a little more encouragement is being given to the development of small modular reactors (SMRs) that can be built in factories and installed where needed.

Nuclear fission is not the complete answer, even if costs can be reduced, because it cannot be ramped up and down easily. Further reliable despatchable capacity is needed to maintain grid security, and the best solution currently available is the gas turbine. Until better solutions are available, gas must surely remain an essential part of our generating capacity.

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 Environment, David MacKay[7]. Unfortunately, the lessons do not seem to be learnt and politicians of all stripes continue to back renewable energy despite the obvious drawbacks of the available technologies.

8. 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. Carbon dioxide can be captured from, for example, by passing flue

[6] REFS

[7] Sustainable energy, without the hot air; David MacKay; 2009; https://www.withouthotair.com/

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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. This in turn can be reused.

This type of carbon capture is what is currently being used and 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 ways have been proposed to achieve this, basically by having a large surface area capable of absorbing carbon dioxide selectively from the atmosphere. In the longer term, new technology to achieve this has great potential to reduce atmospheric CO_2 levels, since it could be deployed anywhere and need not be associated with large-scale sources of the gas.

However, capturing CO_2 is the simple part; to make this worthwhile, it must be locked away, essentially permanently. The approach being followed for this 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 with this approach is that each project is unique, so there are no economies of scale that might make rollout economic.

Governments past and present have offered funding towards 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, compress (not always necessary) 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[8], 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 would be virtually impossible to achieve without a significant contribution from CCUS to allow high-emission industries such as cement to operate. The International Energy Agency published a report on CCUS in clean energy transitions in September 2020[9] at a time when the global goal of net zero was planned to be

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[8] https://www.gov.uk/guidance/uk-carbon-capture-and-storage-government-funding-and-support
[9] https://www.iea.org/reports/ccus-in-clean-energy-transitions

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 unscaleable technologies will, over the next 25 years, be widely used to reduce carbon dioxide emissions. This more than simply picking a winner; it is surely pie in the sky to assume that this could happen without at least the imposition of swingeing levels of carbon pricing. 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.

9. Domestic heating – heat pumps

When we talk about reaching Net Zero, the focus has often been on the electricity generating sector. Granted, this will become increasingly important as electricity is used more and more to replace gas and oil in other sectors but, the electricity grid in the UK is now a far lower emitter of GHG 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 for this, while oil-fired boilers are used by many people outside urban areas.

Replacing these is not an easy task. The two main proposals from the government have been to move from boilers fuelled by natural gas (methane) to ones capable of burning hydrogen, or to use 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 not only has to be from a low-carbon source but 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-effect pumps, since it not usually practical to dig up gardens to accommodate the more efficient ground-effect 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 cost of electricity is several times that of gas in terms of energy output, so the actual cost may not be reduced very much.

The other main 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^{o} or higher, but an air source heat pump is likely to heat water to 40-50^{o}. This means radiators have to be replaced and additional insulation is almost certainly required. 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 £4,000-

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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 their limitations. However, they are also not suitable for use across the complete range of housing. Older, single-brick wall houses may be too expensive to insulate sufficiently, and some high density housing may have insufficient space to 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 60dB). Finally, it is difficult to meet these standards in all blocks of apartments.

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 building is to Passive House standard (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-effect heat pumps, which in nearly all cases will need considerable extra expense in insulation and new radiators. A recent POSTnote research briefing for parliamentarians gives a rather negative impression of both the current situation and future prospects[10]. 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[11]. However, there are also other reasons for the difference. One is the

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

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

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relative cost of electricity and gas. Research by Nesta[12] 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. 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.

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

10. Road transport – electric vehicles

The other major energy-consuming sector of the economy due for decarbonisation to meet the Net Zero target 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 (50-60mpg for the careful driver) and powerful, giving family cars the performance of sports cars of a fifty years ago.

Some campaigners would like to see 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. 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 EVs 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 EV 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 EVs are to continue to use ICEs with bio-fuels or synthetic fuels that are low-carbon or use hydrogen as the energy carrier. The first of these approaches has been approved by the German government following lobbying by German car manufacturers. This allows

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

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continued indefinite sale of petrol-engined cars 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 would 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 EVs. 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 the world has been that battery power is the future. However, EVs 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 EVs 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 EVs 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 ICE car are not as black and white as we 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 EVs, 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 the use of 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

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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, 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 (although town gas, which is 50% hydrogen, was piped to houses for many years before being replaced by methane). Creating a refuelling network could be problematic, but the refuelling itself would be much quicker than recharging batteries, meaning that far fewer refuelling points would be needed than recharging points and use of hydrogen-powered cars would be far more flexible than EVs.

Although in 2023 the government extended the deadline for sales of ICE and hybrid cars to 2035, they also introduced quotas for the sale of EVs The argument was that people should not be forced to stop buying conventional cars, but that manufacturers would be obliged to sell an increasing proportion of EVs in their range from year to year. The target is for 22% of sales to be EV in 2024, rising to 80% in 2030 and 100% in 2035. Manufacturers will be fined £15,000 per vehicle that does not comply with the target.

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)[13]. 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 stretching.

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.

11. 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 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.

Covid vaccines were developed and brought to market extremely rapidly by backing all promising development routes and undertaking clinical trials in a much shorter time than had ever been thought possible. This was expensive, but produced several viable competing vaccines to meet a public health emergency. Light-emitting diodes (LEDs) became the preferred choice of consumers to

[13] October new car market beats pre-pandemic levels but subdued EV growth hinders green goals; SMMT; 6 November 2023

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replace tungsten filament bulbs, despite governments subsidising the rollout of the unpopular compact fluorescent lamps (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 were very 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 the moral high ground by setting targets and the UK became the first country to agree 'legally binding' targets for emissions reduction (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 IPPC tells us is necessary. The naïve assumption is that the rest of the world, including China and India will follow in our trailblazing footsteps.

Although great progress has been made both with domestic GHG emissions (now the lowest since Victorian times in the UK), per capita emissions and 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 to what exists, we have a chance to benefit economically while also benefitting others around the world.

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