



# Science and Technology Committee

## Corrected oral evidence: Long-duration energy storage

Tuesday 14 November 2023

10.15 am

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Members present: Baroness Brown of Cambridge (The Chair); Lord Borwick; Viscount Hanworth; Lord Holmes of Richmond; Lord Krebs; Baroness Neuberger; Baroness Neville-Jones; Baroness Northover; Lord Rees of Ludlow; Lord Sharkey; Viscount Stansgate; Lord Wei; Lord Winston.

Evidence Session No. 9

Heard in Public

Questions 68 - 82

### Witnesses

Michael Liebreich, Chair and CEO, Liebreich Associates.

### USE OF THE TRANSCRIPT

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## Examination of witness

Michael Liebreich.

**Q68 The Chair:** Welcome to the committee's ninth evidence session in its inquiry into long-duration energy storage. We will be hearing from Michael Liebreich, the chair and CEO of Liebreich Associates. The session is being broadcast on parliamentlive.tv, and a full transcript will be sent to you shortly after the session for any minor corrections. If you think of anything later that you did not get a chance to say, or any data or other inputs that you think would be useful to us, we would be very pleased if you could send those in as formal evidence to our inquiry.

We are interested in your views on the role that long-duration energy storage will need to play in the UK's net-zero electricity system. What technologies are likely to play a major role, and at what sort of scale?

**Michael Liebreich:** Thank you for the invitation. It is an honour and a pleasure to be here.

Before I dive into the long-duration storage requirements, it is probably worth touching on a few assumptions about what the system will look like. I spend a lot of time trying to get people to focus on what the energy system actually has to do for us. A lot of people run around with the idea of a magic technology. That is not the right way to do this. We will see a far more electrified system. Currently, we use around 320 terawatt hours per year of electricity, which is down from historical levels by a considerable amount—30% or 40% down from the early years of the century. That will double, or more than double, because of the electrification of transport, heating and industry. I am happy to answer questions on why I think those things will happen.

**The Chair:** I think some of those will get picked up by members of the committee as we go through the session.

**Michael Liebreich:** That is the demand side: lots more electricity, including, very importantly, heating, which is seasonal. That will feed into a lot of the discussion.

On the supply side, despite the failure of the last wind auction round, wind and solar remain the cheapest new forms of electricity that we can put into the system—subject, obviously, to dealing with their variability, which is another driver of storage, although generally not long-duration storage.

There will be nuclear, some bio and some CCS, but these things will be more expensive. With nuclear, we do not know what Sizewell B will end up costing. We do know that with Hinkley, and we know other things, such as that the NuScale small modular reactor has just been cancelled. We are getting a sense, and it is probably safe to say, that nuclear will come in not cheaper than £80 per megawatt hour, so things that are cheaper than that will tend to be advantaged on the system economically.

We need green hydrogen, but at the moment all sorts of use cases are being proposed, most of which will not happen. Hydrogen is expensive and difficult to handle. It is an industrial gas. Currently, we use something like 700,000 tonnes of it—at least, we did before the price spike caused by Covid and the Russian invasion of Ukraine—mainly for fertilisers and petrochemical refining, such as hydrocracking. That is all polluting hydrogen, and we need to clean it up.

Looking at some of the other uses, there are things that are very difficult to decarbonise without hydrogen, such as aviation fuel, maybe shipping fuels, steel, and long-duration storage. There are alternatives to hydrogen, as we will see, but it is quite hard to see how we do those without hydrogen. Looking across to transportation and heating, even in industrial heating there are lots of people running around saying things like you cannot make a brick without high-temperature gas, but most of that is nonsense, I am afraid.

The hydrogen use cases, even if it is a brick, will all happen in industrial hubs. We will not have hydrogen on the high street or in homes. We may have a bit in long-distance trucking, but hydrogen will almost exclusively be in hubs. That defines the sort of architecture that we will see in the energy system, which will be a much-expanded electricity transmission grid. The hydrogen hubs will share hydrogen between them; they will have access to hydrogen in a kind of ring main that is accessed by companies that need hydrogen, so that they can balance their demand. The hubs will be linked to other hubs so that they can balance between hubs when one plant is down for maintenance, for instance. Then hydrogen will go to someone else who needs high-quality high-pressure hydrogen.

The hydrogen system is also likely to be connected to the European backbone. Exactly the same architecture will end up being built in Europe. Right now, Bavarians are talking about hydrogen heating. Physics is the same in Bavaria as it is in the UK, and so is microeconomics. They will also end up with hydrogen hubs and a hydrogen high-pressure connection transmission backbone or grid, whatever you call it. We can connect to that.

We will need long-duration storage in that sort of system, there is no question. The questions should end up being about how much we need and what technology and policy environment we need to put in place in order to make it happen. Some very large numbers are being thrown around, such as 100 terawatt hours of long-duration storage. If you have a system with a lot of wind power, which is essentially what we have—in the winter, when there is heating demand, the solar is not desperately useful, but the wind is—there is a lot of variability. It is not just the famous dark doldrums, what the Germans call the *Dunkelflaute*. You can also have a dark doldrum, then a week of wind, then another dark doldrum when there is very low wind. You could have a bad wind year in which there might be 20% lower wind output. You might have a few bad wind years. If you really want to make your system resilient, you have to take longer-term views on supply.

You also have to deal with the seasonality of demand, particularly if you electrify heat. There is a big difference between summer and winter. People who own gas assets are emphasising that heat load is five or six times the electricity load on the system. But, of course, once you have continued to do energy efficiency in our built environment, which we have been doing reasonably well despite what the press would say, and move to heat pumps, the heat load will not be five or six times the electrical load.

The electrical load will grow overall. I am going to assume that it will double between now and 2050, so the 320 terawatt hours might become closer to 700 terawatt hours. I am assuming that a few per cent of that will need to be served truly from long-duration storage—not a third of it, or 20% or 15% of it, but 2% or 3% of it. There are lots of other ways in which we can balance things. We will do those first because they are cheaper than long-duration storage, which will be quite expensive.

Obviously, anything that can be done with software to balance demand response we will do. We will do that in domestic settings, we will do that in industry. We will also, of course, do it in transportation; there will be all these vehicles with batteries that must be charged smartly, and you can move their charging around. If you know that a cold snap is coming, you could give people incentives to pre-charge public transport—all vehicles, in fact.

We will also do things like thermal storage. It is a lot cheaper to store heat right across the temperature range than it is to store electricity. It is very easy to move the times when you heat your home by a few hours. But you can go bigger than that and store days or weeks in advance, not across the whole economy but in certain pieces of it.

There are other technologies that can do longer-duration storage. Anything under, let us say, 48 hours I assume will be dealt with by demand response, some grid-connected batteries but a lot of batteries in transportation and some thermal storage in industry, domestic and commercial properties, and so on.

My definition of long-duration storage is anything over 48 hours. Then your options really start to shrink, and you come to things like liquid air and high-temperature heat. Battery chemistries are being proposed; they are at early TRLs—technology readiness levels—but they are looking promising using iron-air battery chemistry, which looks like it might work for, let us say, 100 hours/four days.

Then you come back to hydrogen, or to biogas—to molecules. If you go back to the architecture of hydrogen that I postulated, which is hubs connected by a high-pressure transmission grid connected to Europe, hanging long-duration storage off that in salt caverns could make sense, Rough could make sense, and so on. I am looking at, let us say, 20 terawatt hours of storage of that nature.

To be honest, if we came out of this and everybody said, “Do you know what, let’s go for 10 as a starter”, that would be a perfectly good policy outcome for this year and the next few years to carry us forward, to give

us some idea of the scale that needs to be built in the system, to really start pushing policy and technology choices.

**The Chair:** Thank you. That has been very helpful.

**Lord Krebs:** You came up with a figure of 20 terawatt hours, as a “for instance”. The Royal Society report came up with a much bigger number, so I am assuming that you feel that it made some different assumptions from yours. Could you give a little pen picture of what assumptions lead to the big number, and what assumptions lead to the small number, and how robust those are? I do not believe anything that fixes on a particular number, such as 20 or 100, because it will be a band.

**Michael Liebreich:** I mentioned that there are bigger numbers being thrown around. I did not want to shine a spotlight specifically on that piece of work, but since you have, that was Professor Sir Chris Llewellyn Smith’s work on behalf of the Royal Society. On the figure of 100 terawatt hours, he says quite openly that this is worst-case—that he has assumed, for instance, that it is all done through hydrogen in salt-cavern storage and that, at the point when it is needed, there is no nuclear, no interconnections, and no production of wind and solar. I believe that those are the assumptions.

It is marvellous to do a really outside, stress-test case, but real life is not like that. He has also assumed, for instance, that there would be no load-shedding. If all interconnections, whether to our European partners or to projects like Xlinks, a UK project that will be in Morocco—disclosure: I am a small investor in it—switched off at once, we would not be able to rule out load-shedding. This is such an extreme situation. Why would we be getting zero output from any of our other resources? The assumption that the economy has to ride through that imperceptibly is not realistic.

To be fair, I have not done detailed modelling. I am just looking to say that I know it is a lot smaller than the figure of 100 terawatt hours. I am also not postulating a number; I am not saying that it must be 20. You will note that I said that we need to get started. This stuff will take so long to build that there are no regrets to building some number of terawatt hours and starting now, because we will need them. So whether the number ends up having to be 10, 20, 30 terawatt hours by 2050—maybe the good Professor Llewellyn Smith is right and we will need 100 terawatt hours—we will not regret starting now.

Q69 **The Chair:** That is a good point. We need to start now on the interconnectors and nuclear that might reduce our need for long-duration storage. Are there no-regrets investments that we should be making now, and will they have any impact by the early 2030s—both Labour and Conservative policy would like us to be decarbonising our grid roughly within that period—or are they something we should be looking to for 2050?

**Michael Liebreich:** Let me talk about nuclear. I mentioned the cost point that I think we will get to. Nuclear needs to be addressed, because there are so many hopes and dreams around the volume of nuclear, the arrival and the time, and so on. I will come back to transmission and

interconnectors.

I am pro-nuclear, but I am a cold-eyed realist on this stuff. We have seen that it is very hard to add nuclear quickly, and it is expensive. The big projects tend to overrun and arrive late, and it would be foolish to assume that that can suddenly be turned around. They can clearly improve on the cost point of Hinkley C, particularly in the way it was financed, but there is no evidence that it will come in at less than £80, as I mentioned, or even £90—it depends on inflation, and so on—per megawatt hour. Nuclear is also volume-limited.

There are high hopes for small modular reactors; Rolls-Royce has its small modular reactor, but there are others, such as GE. I mentioned the news from the US. The leading, or at least the most advanced in the process, small modular reactor company NuScale has just lost its lead project because costs have gone up.

There is also the issue of how many small modular reactors you would need to really put a dent in power demand. I have not done the numbers for the UK, but I have done the numbers globally. Wind and solar supply broadly 15% of global electricity today. It has taken them 20 years to get there, and that is where we are. It is only electricity, and it is variable. I understand all the caveats; I am just doing some numbers on scale. You would need to build 1,300 400-megawatt small modular reactors like the Rolls-Royce reactor to get the same output of terawatt hours, assuming 90% uptime. You can collocate a few. Maybe you have 500 locations, but 500 locations where you have to be building nuclear worldwide is the sort of scale that needs to happen. Even then, you have only matched the 15% of power that comes from wind and solar.

You could be all for continuing to push for small modular reactors, and I am. You could push for fusion, but you have to be realistic about when it can happen. When it comes to a meaningful contribution to climate, to net zero—"meaningful" being 1% of electricity supply—you are talking about 2040 for small modular reactors, and 2050 for fusion. That would be my judgment.

In the architecture that I described, even though nuclear might be more expensive than a combination of wind, long-duration storage and other techniques to firm the output, it should—and it will, I believe—have an incredibly important role to play. It does not function as back-up for wind and solar—you cannot just turn nuclear on when it is not windy—you must run it as close to 24/7 as you can, because the costs are bad enough anyway. So you are running it all the time and it is more expensive than other sources of power. You might, for instance, be electrolysing hydrogen, and hydrogen will be more expensive than that made from other sources of power—not by much, because nuclear provides electricity and some heat that you can use, but you are losing money.

For four weeks a year, you have those dark doldrums—there is no wind or sun—and you have to dip into your long-duration storage. However, you can also switch off the electrolyzers, refineries, the ceramics plant or whatever else you were using power for during that year, and for those

four weeks, when the wholesale price of electricity goes through the roof, you will make enough money to meet your cost of capital overall for the year for that nuclear plant. So nuclear's role is back-up, in a sense, but you must run it all year and pair it with, generally, industrial uses of power that can be switched off at large scale when you need to. That then makes sense for nuclear.

In the case of interconnector transmission, pretty much all of it is no regrets. If you go from 320 terawatt hours of electricity demand per year to 700 terawatt hours of demand, it is like being back in the 1950s and 1960s, and possibly the beginning of the 1970s, in that growing demand will cover any errors, and all you can do is invest a bit too early. Almost whatever you build will end up having a use on the electrical side.

I contrast that with the gas network, where you have the exact opposite, particularly with the distribution pipes in the ground. Every investment looks like it will be a regrets investment. As Sir John Armitt and the National Infrastructure Commission said in the second infrastructure review a few weeks ago, all the distribution grids will have to be decommissioned. Frankly, we should be investing only in safety-related work on our gas distribution networks as of right now. We should have a moratorium on anything but safety, because, frankly, all the money that is going into the gas distribution network today and being added to the regulatory asset base is a stranded asset, and we will end up paying compensation to those gas distribution companies.

On the transmission grid, fast-tracking the investment case—I do not want to say finessing it, but supporting it and accelerating the planning with nationally strategic infrastructure, transmission corridors, et cetera—makes sense, as do interconnections to our European neighbours and possibly further than Europe. As I said, I am an investor in Xlinks. What you really want to do is interconnect to places that are north-south and so have very different weather patterns, or east-west and so have very different time zones. I find it interesting that, if you can connect to Morocco, you can also connect to Maine, to North America. Those different time zones give you enormous smoothing.

**Q70 Viscount Hanworth:** When people talk about nuclear, they tend to think of APRs—Sizewell C, Hinkley C and so on—and the costs associated with them, but there is a strong opinion that small fourth-generation nuclear reactors could provide the best strategy. There are molten salt, thorium and lead-cooled fast reactors, which can be capable of consuming our substantial stockpile of plutonium, the MOX fuels that we can derive from the waste of EPRs, and, directly, the waste of EPRs. That implies huge efficiency.

Proposals for these reactors suggest prices around £50 per megawatt hour, which comes in below anything that one might associate with a huge supply of renewable power and the adjunct storage. That would be more expensive than what these people are proposing. What is your reaction to that, and, by the way, to the proponents who say that the prototypes should be up and running, if the Government give the

necessary subventions, by 2030?

**Michael Liebreich:** I enjoyed your question, because it took me back to my years studying nuclear power. There are all these technologies, we have settled on a particular technology solution that is not necessarily optimal in terms of fuel and so on.

There are two things. One is the cost. The other is the scaling—the ability to move fast. On the cost, Admiral Rickover described the perfect nuclear reactor as easy to build, very efficient in its use of fuel, and posing no proliferation risk. I cannot remember his exact words, but it is a fantastic beast. But it has also not been built yet. He said that the real nuclear reactors are difficult to build, you spend inordinate amounts of time and money solving problems that you did not even know were problems, and it ends up being expensive and very challenging.

NuScale, the company that has just lost its lead project, was promising nuclear power at \$59 per megawatt hour. It lost the project, because—as it admitted a few months ago—the number would be \$89, after the subsidies from the US Inflation Reduction Act, the Infrastructure Act and so on. I made a back-of-the-envelope calculation that it is really talking about \$130 per megawatt hour, and that is five years before it is built.

**Viscount Hanworth:** It is not a very smart design, by the way.

**Michael Liebreich:** It is not a very smart design, but, as Admiral Rickover would say, there is always the next design that is much smarter until you get into the detail. I am not saying that we should not spend the money and not do it. We should, but we should be very clear-eyed about the tests that we try to get these early plants to meet, and the likelihood of success both in cost and in scale.

Even if the SMRs work economically, how many of them can you build? What is your supply chain? NuScale was the most advanced—GE and a few others were shortly after them in the process—and was hoping to build the first one by 2030. If we can get three small modular reactors of any sort globally by 2030, that will be going some. You then do not have the supply chains for the fuels you mentioned. They take time to build, and suppliers take time to qualify. Every component has to be qualified. So by the time we are building them in series, it will be some years after those first few plants get built.

They start more expensive than the big plants. There is a clue in the name: small. You have to do all the regulatory and qualification work, site preparation and so on, and then you get only 100, 200, 300 megawatts instead of Hinkley's 3.2 gigawatts. The big hope is that they come down a learning curve and, at some point, cross over and become cheaper than gigawatt-scale nuclear. You have to build them in large numbers, like liberty ships, to deliver the benefit. Contrast that with wind and solar batteries, which are already delivering and where the build cycle is one to three years, not six to 10 years at best.

**Viscount Hanworth:** It is notable that half the costs of Hinkley and Sizewell are interest rate costs.

**Michael Liebreich:** It is not half, but your point is valid

**The Chair:** We should move back to long-duration storage.

Q71 **Baroness Neville-Jones:** You said that we need to get going on storage. As somebody who is an investor and adviser in this area, how does the landscape look for long-duration energy storage technologies and companies at the current time, and how does that compare with other clean technologies competitively?

**Michael Liebreich:** If you take my definition of 48 hours-plus, there is almost no investment going into it. I was on the telephone yesterday, coincidentally, with the developer of an iron-air battery, which is 100 hours/four days. That would nudge you over the 48 hours and would certainly be a useful resource for things like tropical storms and perhaps the first few days of a beast from the east, but it will not get you through seasonal variations or long or repeated dark doldrums, and so on.

If you say salt caverns, they have been done: we have hollowed them out deep underground by using high-pressure water, brine and so on. We know how to build a pipeline; there are pipelines with hydrogen of a few thousand kilometres, not more, and there are compressors, so there is investment going into it. Largely because there is such a flurry of investment in hydrogen elsewhere, there is investment going into a lot of its components.

But, first, we need to settle on an architecture. If we are going to do salt caverns, what will we need? We could start with 1 terawatt hour, never mind 10, 20 or 100, but we could say "We're definitely going to do some of it there and have a policy". Private companies will find it very difficult to speculatively invest in it. We saw the whole saga around Rough, just keeping storage for an existing and used commodity like natural gas.

**Baroness Neville-Jones:** Does the problem lie in the absence of a public policy framework? Is that the issue that holds it back?

**Michael Liebreich:** Yes, broadly speaking, if you also count the energy architecture. There is a kind of energy strategy piece and then a public policy piece that would get capital to form around it. If you put both of those under public policy, then absolutely yes.

**Baroness Neville-Jones:** Right, so this is the absence to some extent of the framework within which investors can then really get going.

**Michael Liebreich:** The closest analogy would be something like the US strategic petroleum reserve. Private companies can do all sorts of things, but they will not just go off and do it voluntarily when the returns are so variable and questionable, so long-distance and possibly not particularly high.

**Baroness Neville-Jones:** We have been told that long-duration energy storage is not as intrinsically attractive to investment companies when compared with other types of clean technology. Do you agree with that?

**Michael Liebreich:** I do.

**Baroness Neville-Jones:** So what do we need to do to change that? Do

we come back to what you just said about it being the absence of the public framework?

**Michael Liebreich:** Let me explain why it is unattractive, because that will lead into what we might do about it. Long duration storage is unattractive because you cycle it very infrequently. It is very capital intensive, which means that you are talking about a lot of money for relatively small outputs of energy, and you do not cycle it often. If you put a battery into your car and use that car every day, you are cycling it every day and might charge it every two or three days. There are models for things that we use often.

**Baroness Neville-Jones:** You could cure that problem by the type of contract that you sign.

**Michael Liebreich:** Absolutely, which leads me to who you are signing that contract with. Again, what would a private company do? It might be a utility, for instance. If you look at who needs electricity and who is going to sell it, the utilities will happily sign up homeowners, businesses et cetera to sell that electricity. Let us say that once every year there was a week when you could force them to cover themselves by doing a stress test on their purchasing: "Have you procured enough power, and can you get through a beast from the east?". You could ask a Bulb Energy—just as an example—whether its balance sheet would get it through a price spike and a beast from the east, so you could stress test that.

But what happens when there is a bigger problem once every five or 10 years, possibly driven by odd weather? We also need to realise that it could be driven by cyberattacks or by all those marvellous new small modular reactors developing cracks at the same time. It could be about fleet recalls or solar flares. I am a security hawk, so one reason why I want to get going is because we have sucked out of the system all the stored piles of coal, and we are sucking out storage in natural gas with things like Rough but also line-packing—the gas in the pipes. We are moving to electric vehicles, so we lose the storage of petrol and diesel.

Private companies will not come in and make up for that. I do not want to call it taking a chance, but on these longer duration problems they will most likely underprovision and undersecure themselves.

**Baroness Neville-Jones:** You are saying that it does not sound like a very attractive investment, so what do we have to do to ensure that we do end up with some storage?

**Michael Liebreich:** There is a role for government because it is related to security and resilience. Once you have the architecture and know that you want some long-duration storage, you could envisage different ways. You could procure for it directly by government. You could put a levy on to anybody who might dip into it and use it. In fact—I will pull out a number—you could do a one-10th of a cent per kilowatt hour resilience levy, put that into a fund, and then procure it centrally, in the same way that the strategic petroleum reserve is procured.

**Baroness Neville-Jones:** How would you decide between these various options?

**Michael Liebreich:** If it was on the funding side, I would do some very deep studies and use some of the marvellous consultants that, luckily, we have in the UK. London is the world centre of doing energy studies, some of which even turn into reality on the ground eventually, although most do not. I am being flippant and should not be; this is too serious a question. It is not a simple question, though, because there are unintended consequences.

There are justice questions. We do not want to just push up the cost of electricity to the vulnerable. There is a battle to be had with industry. The game of energy-intensive industries is to try to get five- or six-nines reliable electricity for themselves as cheaply as possible by lobbying for the whole system to have five- or six-nines super-resilient electricity, even though most of us do not need that and a lot of it can be shifted around temporarily with demand response; demand could be moved around. However, they try, in a sense, to make the system more expensive, because if they had to pay for what they need, which is a lot of very reliable electricity, it will make them uncompetitive internationally.

So there are a lot of complex questions to be worked through. My flippant answer is that I would do some big studies, but it really does require some proper laying out of alternatives and evaluation and thinking about the unintended consequences—and on both sides. There are two sides to it: how you would disperse the money, and then how you would fund the money. The funding will be through some kind of levy on some subset of energy users, I am guessing, maybe supplemented through taxation, but how you disperse the money is a technical question about how big you want your storage, where, how full you want it to be and so on. Who manages it and what is the governance? When do you release and charge it? Those are the sort of questions that need to be worked through with the energy system experts.

- Q72 **Lord Borwick:** When you are talking about this, are you not reinventing the insurance industry? The earthquake insurance industry has very similar products, which we are really pretty good at writing in the UK. It is low probability and very high-impact stuff. If everybody grew the insurance industry, could we not afford this? Would that not be a better way of funding it, rather than cap and floor and so on?

**Michael Liebreich:** You make a very good point. Yes, some of it can be funded through the insurance industry. If people are paying a tiny bit, you could put that levy in and call it an insurance premium. Though the insurance industry also invented things like moral hazard. Someone has to make sure that engineering is required to be built. The insurance industry, to my mind at least, is about who compensates when things go wrong. However, this is about trying to stop things going wrong; it is about funnelling money into actual engineering and building things.

There is no question that the insurance industry can play a role, some tranche of variability. For instance, if you use nuclear in the way I describe and a company is paid to switch off its industrial process for a period while the lights and heating are kept on and transport is kept

running, and if the payment for that is insufficient, that could be supplemented through the insurance industry.

But for the really catastrophic gaps every few years, even in the insurance industry the state is the insurer of last resort. We have seen that across earthquakes and the nuclear industry, et cetera. I think it is about slicing and dicing.

**Lord Borwick:** Every country has to face this problem, but is there any structure that we can copy from anywhere else? What is America doing?

**Michael Liebreich:** In America, other than the strategic petroleum reserve—and, interestingly and increasingly, the strategic critical mineral reserves that it is building—on this topic I do not think we can look there for an example. America has the huge disadvantage that the transmission grid is regulated at the state level, unlike gas pipelines. It has a very Balkanised system for this. My gut tells me that Switzerland and Singapore are probably the only two countries that are putting proper time and thought into energy system resilience. I do not know that they have answers.

**Lord Borwick:** But Switzerland has the advantage of hydro. Singapore has none at all, presumably.

**Michael Liebreich:** Switzerland has a lot of hydro, exactly, and Singapore does not. Like I said, I do not think they have the answers, but I know that they are further ahead in thinking about it. The electricity market authority in Singapore is very concerned about resilience.

I want to put one other thing out there, maybe just to note. Every country is going in the same direction with more electricity, more variability, the same risks and the same sort of volatility in geopolitics. Every country faces a lot of the same challenges. We have some unique strengths in this country. It is not just that we are really good at engineering and things like gas turbines. You have to not only store hydrogen but turn it back into electricity, either via a fuel cell or turbine, or maybe the reciprocating engine that I think Professor Llewellyn Smith mentioned. We are good at that kind of stuff. We have the City of London and the insurance companies.

We have huge salt cavern storage capacity, so there is a world in which we get this right and we are the storage lungs of Europe in the same way that Norway—Switzerland can store for itself—is acting as the lungs through its hydro resources. It is doing some pump storage, but a lot of it is about keeping its water up in the reservoirs and then releasing it when Denmark needs electricity.

You can envisage a world in which Belgium does not have storage capacity, or has insufficient capacity, and would pump its hydrogen into our storage or pay us to store it and return it via a backbone. That is a very attractive prospect. Germany has salt caverns, as do some other countries in the east of continental Europe, but not everyone does. In a world where everybody needs long-duration storage, perhaps we should be thinking about this on the front foot and leaning into it, rather than just reacting and saying, “It’s terrible. We have to solve this problem”. It

could be a substantial opportunity, and fantastic for our own resilience in that situation. Singapore is definitely thinking about its resilience, coming from being the trading hub, and is trying to establish storage.

There are other things that you can store—not just gaseous hydrogen, which we could do but Singapore could not; it does not have the geology—you could store ammonia, methanol or liquid organic hydrogen compounds—things that you can put into big tanks and store like that, which Singapore has quite a lot of. It would perhaps fit more naturally for Singapore to store a liquid derivative of hydrogen.

It has to be noted that the alternative to all this is that we just use natural gas unabated and say, “If it’s 2% or 3% of our electricity, we’ll just use gas and then do offsets or let our kids figure out how to deal with it”. What you will not do for that 2% or 3% is carbon capture and storage, because that is a huge amount of infrastructure to build for use just 2% or 3% of the time. If it is zero-carbon long-duration storage from natural gas, it will be in the form of blue hydrogen; in other words, you get the natural gas and take the CO<sub>2</sub> out, you do that 24/7, use the carbon capture assets a lot, put the CO<sub>2</sub> under the North Sea and store the hydrogen, or a derivative of it, for long duration. So it could be as hydrogen gas, and in other countries it could be as liquid.

My sense is that our opportunity in the UK is gas, because storing it in those salt caverns will be cheaper than anybody who has to store it above ground or as a liquid. The losses in making a liquid derivative and turning it back into electricity will be enormous.

**Lord Borwick:** But it would not be a zero-carbon solution to this problem. You would be producing some kind of carbon.

**Michael Liebreich:** Yes, if you were to use natural gas unabated, as I mentioned—it won’t be abated—you release the CO<sub>2</sub> and buy some offsets or whatever if you have to. Ammonia could be zero-carbon, so you could make ammonia. The difficulty if you decide to do it as ammonia is that you have a 20% end-to-end efficiency. If you do it as hydrogen, you can have a 30% to 35% end-to-end efficiency. Turning ammonia back into electricity becomes really inefficient.

If you store it as methanol, you would need a source of carbon. You could use a bio or direct-air capture, which is very expensive. You could use a direct air-captured carbon molecule to make methanol or methane. There are people suggesting that when you generate you could capture the carbon and cycle it back; you would burn your methanol but extract the carbon from that combustion. I do not think that will happen, because you would be using carbon-capture equipment just for the 2% of the time when you dip into the long-duration storage. I think you are more likely to use a bio-based carbon molecule to make methanol or methane. Then, if it is released when you burn it, so be it; that is where it came from.

**Q73 Lord Sharkey:** The long-duration energy storage industry wants a cap and floor subsidy mechanism. The Government have said that they are minded to do that in the case of hydrogen storage, although they have not committed themselves to other kinds of storage. Do you have views

on this as a subsidy mechanism for long-duration storage, and how should it be designed to ensure that it supports a sensible deployment of long-duration energy storage?

**Michael Liebreich:** This goes back to my point about these things being complicated in their design. When you say a cap and floor, fundamentally I would be minded to agree that that is a good way of doing it. Why? It is because you need a minimum return or you do not get the capital formation around the solution, so you need some kind of guaranteed minimum. Equally, if for some reason we use it a lot and the price of whatever it is goes through the roof and people make out like bandits, that is just economically inefficient and socially wrong.

**Lord Sharkey:** There are ways of mitigating that.

**Michael Liebreich:** Right, and a cap and floor approach is one of them. You claw it back. I would lump them all in some ways under cap and floor. The question is: a cap and floor on what? Is it just on the production of hydrogen or use of hydrogen? Is it on the storage of hydrogen or on capacity?

In any energy system there are always two characteristics: how much energy does it store, and how quickly can it then feed that energy back into the grid? There are terawatt hours, but the terawatt hours also have to be able to feed back at gigawatts. Ultimately, you need both: you need the terawatt hours to get you through the season, or whatever it is, and you need the gigawatts because you cannot trickle it out so slowly that we are load-shedding. Detailed design is required before I can say, "Yes, that's a fantastic idea", but in principle, yes, you need a minimum return on capital and there should be some mechanism to stop people from profiteering.

Q74 **Lord Sharkey:** Could I quickly move away from hydrogen? You have said that it is possible that compressed air storage may be cheaper. Can you expand on that a little?

**Michael Liebreich:** There is compressed air, but there is also liquid air. A company called Highview Power is very advanced on that. In some ways, liquid air looks more promising just in terms of how much equipment you have to build for how much energy you get to store. For compressed air, it is more limited: it would typically go down into a cavern or natural formation at these sorts of scales, and then it becomes very lossy.

Liquid air is very promising. It has a good round-trip efficiency in certain circumstances. Without doing too much thermodynamics, you take the heat out of the air when you liquify it. If you then discard it and the time comes when you need to generate power and you want to drive a turbine, the liquid air just sits there while heat slowly percolates in, and that does not meet your demand. If you have stored that heat and can push it back in quickly, then, of course, the air will regasify and you can drive your turbines, and you are off to the races. The problem is that that becomes a complicated system, because you now have to store the heat,

and you cannot store it for five years like you can with hydrogen, natural gas, biogas or whatever in a storage cavern.

So there are limitations. It is very steel-intensive and at a higher cost point because of its complexity and so on. That means that, if it is going to serve a role, it will have to cycle multiple times a year—not just once a year, every six months, or every two years or five years. If you have something expensive, you need to use it quite a lot. It is perhaps more in competition with those iron-air batteries that I talked about, which do 100 hours. If we had them, they would be very useful, but they do not fully answer the question. In Professor Sir Chris Llewellyn Smith's report, he says that the 100 terawatt hours will come down if we get more storage that we can rely on in the system with solutions such as liquid air and iron-air batteries. I think it is very promising.

**Viscount Hanworth:** Do you have a figure for the half-life of energy in heat storage?

**Michael Liebreich:** I am not a geologist, and I am always careful when I hear claims. My first question is, "Who's making the claim?" If it is somebody who owns salt caverns saying, "Oh, yes, you can store it for ever", I would want to do more digging. My understanding is that, if you go down deep enough, the pressure on these formations is so high that it stays there. It is not like you have lots of cracks and the hydrogen is seeping out. I am sure there is some level of loss, but will you lose, say, 20% a year? I believe it is much less, but it needs to be due-diligenced.

Q75 **Baroness Northover:** I am following up on how we get this delivered and the funding. Can the UK Government rely on the market to deliver the scale and type of long-duration storage needed if a subsidy is in place, or should they develop their own state-owned and state-run "strategic reserve" options? You briefly referred to these in relation to the United States. Are there models for how such a strategic reserve could be run and funded that we could learn from? Again, you have partially answered this.

**Michael Liebreich:** Thank you for the question. As I have already alluded to, the private sector will not spontaneously decide that it needs to deliver one or two weeks' storage. It will invest in things that it can cycle frequently enough, where there is a market, such as arbitrage opportunity between, say, night-time and daytime, or where there are capacity payments that are ultimately levied on electricity users, but through a policy mechanism to pay for them. We absolutely need payments to be mandated, so it's the policy framework that has to deliver the pricing or funding to the solution.

The state does not need to own the solution, and I would be very much against that, but then we would be getting into political philosophies. I do not have an issue with private-sector companies making profits as long there is competition between different companies to provide the service; otherwise, it starts to get into PPP-type discussions. But I do think that it is possible to create a competitive market for the provision of long-duration storage. If it is salt caverns, we will need hundreds of them. As

long as you make sure that nobody owns more than X per cent, you will have competition between different providers.

The pipeline network to get the hydrogen into and out of those resources would look more like a monopoly. We have approaches, whether through the national grid for electricity or the gas transmission pipeline networks. The regulators have substantial experience—most good, some bad—of doing that. We have the models to regulate the bits of that system that are a monopoly. It all has to start by understanding the architecture.

There is the question of whether you could do this in a technology-neutral fashion. It will be very difficult to do that. It sounds great, but in the detail of energy systems, as soon as you specify what you need, it tends to tilt it towards one technology outcome. There may be scope for some competition, but, for instance, if liquid air is doing one to four days and hydrogen is doing two weeks, two months or two years, pretending that they are in competition will create a lot of regulatory overlay. In the same way, the attempt was made to push Hinkley C into the same EMR framework as wind as solar, but they are so fundamentally different in their risk and output that, frankly, that was a waste of a lot of everybody's time.

For me, it is a question of the private sector delivering, but in a framework that is very much public, where the regulations are creating the pools of capital or revenue that they go after.

**Q76 Lord Krebs:** Thank you for your responses so far. When you started out, you talked about fitting the question of long-term energy storage into the broader question of what we want our energy system to look like. We have repeatedly heard during the inquiry that big strategic decisions about energy infrastructure, and what the system as a whole would look like, need to be made in order to give security to investors. We heard from Nick Winser about his proposal for a strategic spatial energy plan. Do you think the Government are doing enough to set out their big-picture vision and the strategic plan that will give investors confidence?

**Michael Liebreich:** It is a great question and a great topic. The idea that the market will figure out energy choices does not work, because these are vastly long-duration and capital-intensive projects with security implications, and they interact: you cannot have an electric car charging system and hydrogen cars. There are some co-ordination issues. So having a strategy is a necessity.

We are moving in the right direction, in some ways. There is an understanding that net zero on the grid by 2035 will require vast amounts of added transmission, which is probably not physically possible given the supply chain, and 2030 becomes even less conceivable. But at least there is an understanding that we need to add vast amounts of transmission to the grid. We kind of know what we are building, with one exception, which is hydrogen, where there are still far too many uncertainties that could be shut down, as I have tried to lay out. My way of doing that would be hubs connected by high pressure and so on. It is not necessary to leave open questions on hydrogen heating to 2026; it

would be possible to move much more quickly. That would really help focus a lot of minds and resources, because then we would know what we are building. At that level, yes, we need an energy strategy.

There is a philosophical element within that: do you then centrally plan it? If you set the direction, there is a question about how you deliver it. Do you do it by light touch, providing price signals, or do you, Nick Winser-style, say, "There is a power corridor, and we'll do this"? In a way, as I have said, it does not matter on the transmission side, because there are very few regrets. If we built an interconnection to country X and it was not immediately used, it almost certainly would be in due course.

Overall, however I am a big believer in the role of price signals. When we moved from feed-in tariffs and contracts for difference with prices fixed by civil servants to auction rounds, we saw the price of renewables drop. I was tracking that; the business I was running at the time, New Energy Finance, tracked that around the world. Every time a country moved from a feed-in tariff to a reverse auction, over the next three years the renewable costs dropped by half.

Price signals matter, and not only for getting an overall price signal into a sector. We should also be doing everything in our power to get locational and temporal price signals all the way end to end, from the wind farm or nuclear plant all the way down to the user. We have this absurd situation right now where there will be lots of wind in Scotland and so the electricity price goes to low or very low. Now we have these Octopus Agile Tariffs and OVO Energy, and so on, doing extraordinary work, but people are being told to charge their car or run their heat pump in the south. However, the electricity is not getting to the south; so National Grid in the last hour is having to tell gas-fired power stations to fire up and industry to reduce demand. That is absolutely mad. The reason is because there is no price signal; there is nothing to stop that happening.

There is this thing going on called REMA—the review of electricity market arrangements—and it is critical that locational marginal pricing is at least kept in that. There is a move to say that it is too complicated and that it will drive up the cost of capital for generators. It will not, and there is a lot of academic work behind it.

Once you get that local price signal, you get over the nimbyism, because if you accept the wind farm, the solar farm, the pylons, you will get cheaper electricity, maybe even free electricity for a quarter of the time, and suddenly the calculus locally changes. You are not getting a wind farm, solar farm or pylon to help someone in Scotland or, if you are Scots, to help someone down in the south. You are getting it potentially to help yourself. Also, if you get those very cheap prices for a quarter of a time, that is the price signal that will get you to buy a heat pump or an electric car. It is not the subsidies that we are currently throwing at people, but the price signal. That is the way to do this stuff. That was a short political advertisement for markets and price signals.

To come back to your question, yes, we need a strategy, but let us make sure that the strategy does not obliterate the price signals.

**Lord Winston:** Talking about strategy, there is a huge interest in, and some understanding of, climate change and young people are demonstrating. There is absolutely minimal knowledge about long-term energy storage, which clearly is really important. Do you not think that part of the strategy should be to look at public engagement? People do not understand that we are wasting energy on the national grid, for example, that we are not storing. What is your view on that?

**Michael Liebreich:** I would absolutely back anybody who can help to increase the levels of knowledge about the system. The debate on hydrogen is a classic example in my mind. Why do we have this hysteria about hydrogen? The answer is that we have people who would love there to be an easy solution. There is also political expedience; easy solutions are easy to sell. You have a lot of self-interested people promoting solutions that I believe they know very well will not work. All of that is on a substrate of a lack of STEM knowledge and understanding.

It is very difficult to explain. It is tremendous to have an opportunity like this with an audience that is very much up to speed on and engaged on the issues. But if you try to talk about hydrogen in salt caverns down the pub, it is hard.

Q77 **Lord Rees of Ludlow:** This question follows on from Lord Winston's, really. Obviously, people's main concern is not to be left in the cold and dark in extreme weather. Should we also be worrying—you mentioned cyberattacks—about the distribution system, which could fail? We have not really discussed that. Is the distribution system resilient, or are there possibilities of cyberattacks or breakdowns that could have a major impact on the distribution of electricity even when the supply is in principle sufficient?

**Michael Liebreich:** I think you should be worried about all of the above. Most power cuts are caused by the distribution system; it is a tree falling on a line or a storm locally. Around the world to-date there have been no power cuts that I am aware of caused by the wind just not blowing or the sun not shining. They have coincided with those things happening, but when you go into the detail they have always come down to bad planning, bad algorithms and bad policy environments. Generally, with things like piles of coal freezing in Texas, the wind gets blamed, but in the end it is not that. But we should be worried about all risks to the system.

There may be a meta-question behind your question, which is: should we keep two distribution systems—a gas distribution system and an electrical distribution system? The answer is categorically no, first, because the gas distribution system arguably prevents us ever getting to net zero just because of the blue hydrogen, et cetera, that we would be putting into it. But also, it is much better to put all your eggs in one distribution basket and mind the basket— which means invest.

For instance, even if there is a power cut, make sure that it does not cascade across the system. Last year, there was a power cut that shut down the rail network. How can that be? How can we not protect the

power supply to our critical infrastructure, like trains? We need much more intelligence—by the way, another thing that the UK is good at is the software—to protect certain types of demand even if, in a sense, we have to sacrifice other parts of demand.

I think you are right. I worry about all of the above. I am a resilience hawk.

**Lord Rees of Ludlow:** So you are saying that we need more resilience and redundancy in the distribution system.

**Michael Liebreich:** Yes, we need resilience—smarts and redundancy. Redundancy does not mean duplicating entire systems; it means redundancy cleverly designed into systems, making sure that civic infrastructure such as schools could ride through a power cut of a certain length—12 hours, 24 hours—those sorts of things. But we have to invest. Again, private companies are not suddenly going to say, “Yes, we’ll put that in place, because once every five years everybody will love me because my supermarket car park is where they will be charging their phones”. They have to be remunerated for that sort of thing.

Q78 **Lord Winston:** We are well aware of your voiced scepticism about the uses of hydrogen. Would you be good enough to give us a brief comment on the challenges facing the green hydrogen industry at the present time?

**Michael Liebreich:** I have been accused of hating hydrogen, but I do not hate any member of the periodic table. What I am is very sceptical about certain uses for hydrogen that are heavily promoted. I have developed a thing called the hydrogen ladder—I would be very happy to provide the latest update of it—where the things we have to do with clean hydrogen are up at the top. Broadly, they are things that we are currently doing with dirty emitting fossil hydrogen, plus a few things like steel, aviation, shipping and long-duration storage. Then, at the bottom, there are things like hydrogen buses, taxis and trains, which, to anybody with a thermodynamics or a micro-economics background, are just catastrophically poor uses of resources. That is my scepticism.

The current problem with green hydrogen is that only a very small number of projects are going ahead, broadly because green hydrogen is expensive. If you are a fertiliser maker using grey hydrogen, which is natural gas hydrogen, and doing that for, let us say, \$1.50 a kilo—I apologise for using dollars—and somebody comes along and says, “I want you to use green hydrogen”, and it is \$3.50 a kilo, you have to find \$2 per kilo to justify that. That is what the policy environment has to provide, through a carbon tax or some other mechanism.

The recent Hydrogen Energy Ministerial in Japan—it was the sixth Hydrogen Energy Ministerial—came up with a target for 2030 of 90 million tonnes of clean hydrogen. Hydrogen demand today is about 100 million tonnes. If you are not an engineer, maybe that order of magnitude sounds feasible for 2030—it is just growing overall demand to 150 million tonnes and for 90 million tonnes of it to be clean. But if there is that \$2 disparity per kilo on the 90 million clean tonnes, 2 times 90

million tonnes, which is 90 billion kilos, is \$180 billion per year of shortfall, and you need 10 years of that. To pull the trigger on those projects, you will need project finance on a 10-year offtake. That would require \$1.8 trillion on the table today to hit the target. So we see all this excitement about projects, but a miniscule minority of them are getting through to approval.

**Lord Winston:** Does that immediately inhibit the chances of using it, either for heating for domestic use or, indeed, for travel?

**Michael Liebreich:** That is the current situation in the hydrogen industry, which has become so overhyped. For instance, when you hear the proponents of hydrogen heating saying that the boiler will cost the same, they do not want to say, "But the gas will cost two to five times as much". It would probably be five times as much if it is green and two times if it is blue. They also do not want to say that it produces nitrous oxides when you burn it or, very interestingly, that if you use blue hydrogen—by the way, blue hydrogen is the only way we will get to the volumes required—you will need to import one and a half times as much gas, simply because you are taking something out, the C from your CH<sub>4</sub> or natural gas, storing it underground and burning the rest. When you do all the chemistry, stoichiometry and all the energy balances, it turns out you have to buy one and a half times as much gas. So our import dependency on gas will go up and we will be consigning people to using a gas that, at the minimum, is twice as expensive as the current supply.

Heat pumps are complicated and will cost more to install, but at least they offer the chance that we will ultimately spend the same amount on heating. With hydrogen heating, that is simply not the case. Some of the promotion is absolutely disingenuous. You will have seen in the newspapers all the stories about how heat pumps do not work and that they are too noisy, et cetera. A campaign by a Birmingham-based PR company called the WPR Agency was funded by the Energy and Utilities Alliance, and the PR company boasted on its website that it had been given a brief to "spark outrage" about heat pumps. That is why this coverage is out there in the papers. It is not an accident.

**Lord Winston:** This comes back to public engagement.

**Michael Liebreich:** It comes back to that, but we have to understand that the gas industry is—how can I put it?—fighting pretty dirty. It is classic predatory delay or merchants of doubt stuff, and it is happening in this country and happening today.

Q79 **Lord Wei:** Building on that last point about heat pumps, is there a risk that you could have the same problem when using hydrogen for heating or transport, where it does not work, it does not add up or it causes costs to increase? Might that then have a negative impact on the overall move to using hydrogen in areas like long-term storage? What can policymakers do to mitigate that? Should we completely downplay these other uses and focus on long-term storage to avoid that knock-on effect, PR-wise and so on?

**Michael Liebreich:** Thank you for that question. The substrate of it is: how much synergy is there between different uses of hydrogen? I invented an analogy, which is going around the world, of hydrogen as the Swiss army knife, because you can do everything with hydrogen: you can heat or do storage, you can use it as a chemical feedstock, you can fly an aeroplane or drive a car. It is fantastic.

The problem is that the analogy has gone out over its skis. It has run ahead of itself, because I use that analogy to explain that we will not do everything with hydrogen that the chemistry of hydrogen would allow, in exactly the same way that, if you have a Swiss army knife, you do not use it to cut your hair. You do not use it to butter your sandwiches or prune your trees. You may have the little saw or the little scissors, but you do not do it. Why? Because there is almost always something cheaper, safer and more convenient. That is the lesson of the Swiss army knife analogy in hydrogen. We will use it for things where it is the only solution or, very rarely, where there will be an alternative, but it is hydrogen that is cheaper, safer and more convenient. Generally, we will use it for things that you simply cannot do any other way.

Your final question was whether we should rule out the use cases that do not make sense. The answer is yes, absolutely, because that synergy is incorrect. There is synergy between the use cases of hydrogen that happen in heavy industry in hubs, where, if you are making steel but need to maintain a blast furnace and if somebody else is using hydrogen locally—maybe they are making fertiliser or aviation fuel; they might be using it in Stanlow refinery—it is very helpful to have a number of off-takers in the same place, or a pool of engineers who are skilled in hydrogen safety, et cetera. At industrial hubs, yes, there is synergy, but that does not mean that we need hydrogen in the domestic gas grid or at fuel stations.

By the way, fuel stations are an example of how unsuited hydrogen is to distribution. If you want hydrogen in heavy goods vehicles, which is one of the use cases that might just have a use for it, how are you going to get hydrogen to the fuelling station? You can use a tube trailer, which is a big trailer with cylinders of hydrogen. Guess what? They carry 400 kilos of hydrogen on a truck that, if it was carrying diesel, would carry 25 tonnes. You need 16 to 18 tube trailers to replace one diesel truck. You may be the council leader in a village and have a gas station in your village, and suddenly there are 16 to 18 times more deliveries, with 16 to 18 times the risk and traffic. This is not what the industry wants to talk about. It wants to talk about mitigating climate change and all those good things, but it is in the detail where hydrogen falls down. There is the cost too, of course, 16 to 18 times the cost.

When you look at heating, hydrogen naturally escapes more; it is an escapee little molecule. It embrittles metal, particularly steel. It also has a very high ignition envelope. A low concentration or a high concentration can explode, whereas with natural gas it would only be a medium concentration. So if you do nothing and just change the burners and put it into homes, four times as many people would be killed and seriously

injured. Actually, there would be 12 times as many explosions, but most of those explosions just go upwards.

You can—HSE is involved in this work—make hydrogen as safe as natural gas, which, by the way, is not fully safe; ask the people in Jersey where there was recently a terrible, tragic explosion. However, when you go into the details of what is required for safety, money is needed for changing out components and adding excess flow valves. If you want to make it passively safe—in other words, it is safe in a power cut, when your children are upstairs, if your house is empty but your neighbours are still around—you have to knock a hole in your wall four inches by four inches. That is what the engineers say. Work done by Arup for the Government said that the only way to make it passively safe is to have an unclosable vent in each room with an appliance and each room with substantial pipework.

You can then get into nitrous oxides. Do you want to use a hydrogen cooking hob when 13% of childhood asthma in the US is caused by indoor hob cooking? We do twice as much of that in the UK, so presumably indoor cooking is responsible for 25% of childhood asthma in the UK.

If we are going to change a system, let us change it to one that is inherently better in all dimensions. If that requires investing more in making sure that single system is resilient, we should be doing that. It will still be cheaper than being stuck paying two to five times as much for the fuel for ever, which is what you will do if you have hydrogen heating.

**Q80 Lord Wei:** From a policy perspective, would you therefore be advocating a ban, just letting the market—because of the costs involved—wash out, or not favour it? What practically could policymakers do to skew towards the better use cases?

**Michael Liebreich:** I would pull forward the decision. I would say that hydrogen is for heating in special cases only. I would put it on a special regime and effectively rule it out. I would say right now that we are not going to do it. That clarity alone will help.

Failing that—this is very interesting—to get to hydrogen heating, the ban is not actually relevant. The proponents of hydrogen heating are saying, “Just leave people the choice. Let them choose”, but you do not choose hydrogen heating in the same way you choose electric heating. By the way, it is not just about heat pumps; there are also electric boilers, so for smaller properties it might not even be a heat pump. But it is a personal decision: I can decide today to spend the money and go to electric heating.

Only at the level of a gas distribution point like a village can you decide to go to hydrogen. The issue in Ellesmere Port, and now in Redcar, is that people are beginning to understand that you have to switch off all the homes that are on gas. They will have no heating or cooking until you can switch them back on, converted to hydrogen. You cannot stay with natural gas at that point; you have to go either to hydrogen or to electric. At that point, people have to be informed enough. If you want to say, “Let’s have a choice”, those people must be given a vote. This will affect

their homes, insurance, resale value, energy costs, and their safety and their kids' safety. They have to be given a vote, but it has to be at the level of the 2,000 homes that are affected.

Democracy without information is pointless, so they have to be fully informed about the cost or likely cost of the hydrogen. You cannot go into that vote not talking about nitrous oxides, safety or the vent in the wall. People are now being told, "We can use sensors instead of a vent". Fine, but when your hydrogen sensor goes off and your kids are upstairs, what do you do?

This information has to be provided and then you can talk about choice, but only at the level of that gas distribution point. So yes, I would pull forward the decision and say, "Forget hydrogen for heating". I would put a five-year moratorium on any investment in the gas distribution network that is not safety related. I would have an explicit discussion about the terms under which our gas distribution pipes are decommissioned. Do you just fill them with foam and leave them under the ground? Who do you pay? What sort of compensation do you pay?

The way it works right now is that, if they put money into the ground and invest in gas distribution for conversion to hydrogen—they have to be allowed to do that, because until 2026 hydrogen heating is a potential outcome—and if that investment gets added to their regulated asset base, they earn 6.4% on it for 45 years, out to 2068. There should be a moratorium on that: just stop doing it, because what will happen when they pull out those pipes? They will ask for compensation.

**Lord Wei:** And you would say long-term storage only, or would there be any other use cases for hydrogen?

**Michael Liebreich:** I will provide a copy after the meeting of the hydrogen ladder. I would focus on the use cases at the top. In petrochemical refining and fertilisers, where we use hydrogen today but it is fossil, you would get clean hydrogen. There is also steel. There are lots of use cases as well as long-duration storage. Steel is also very interesting.

**The Chair:** You have listed those for us and said that you would send us your updated hydrogen ladder, which would be really helpful for us.

Q81 **Viscount Stansgate:** In a way, you have been talking about the question I am about to ask you up to now. The concept of a hydrogen economy has been around for a long time—I think it goes back to William Stanley Jevons in 1865. What do you understand by the phrase "a hydrogen economy", and why do you think that it has not materialised yet, or will?

**Michael Liebreich:** Thank you for the historical reference to the great energy economist Stanley Jevons. My understanding of a hydrogen economy is that hydrogen is pervasive through the economy, it is not just an industrial gas. We do not talk about a fluorine economy; there are all sorts of gases that we do not refer to that are used in industry.

The hydrogen economy is postulated as a kind of replacement for the fossil fuels that we use in everyday life. I think we will have a deeply electrified economy. Even then, I would not call it the electric economy, but we will certainly use much more of that than we will hydrogen. The idea of a hydrogen economy relies partly on it being pervasive and, I think, on there being synergies between the different uses: that if there is hydrogen everywhere, there are synergies once you have pervasive distribution and the costs will be lower because of that. I disagree with that. In statements by Chancellor Scholz, for instance, he talks about the hydrogen economy in heating, fuels and industry. That is the hydrogen Swiss Army Knife model I mentioned. The hydrogen economy is if we did all the things we could with hydrogen. That has not happened because hydrogen is an expensive, difficult to handle, explosive, escapee embrittling gas.

By the way, to the point about public engagement and education, a cubic metre of water weighs 1,000 kilos, a cubic metre of diesel weighs 750 to 800 kilos, and a cubic metre of liquid hydrogen weighs 71 kilos. So if you think you are going to put liquid hydrogen on a ship, you will not, for the same reason that we do not put expanded polystyrene on a ship. You make expanded polystyrene where you use it, because you do not transport very bulky things around, particularly not at 20 degrees Kelvin—minus 253 centigrade—when they try to escape, embrittle and explode. Even a hydrogen leak on those tube trailers I mentioned earlier, at 700 bar, would very likely self-ignite because of physics—the Joule–Thomson coefficient. There are very difficult physics around hydrogen which mean that it always be an expensive solution—expensive not so much to produce, as I think we will produce very cheap hydrogen, but expensive to move around and very expensive to use.

We can make lots of things work. I could make you a racing car that uses coal and steam. It just would not be a very good one and would be very expensive, and it would break all the time. There are good reasons, grounded in physics, for why hydrogen does not and never will play all the roles it theoretically could. You will never have hydrogen fuel-cell cars, although our chair here may disagree. It is just that these are worse cars. They are full of hydrogen cylinders and have lots of moving parts. These are just worse solutions than electrification.

**Q82 Lord Holmes of Richmond:** Thank you for your evidence this morning. We will be questioning the Minister presently and completing and publishing our report, with recommendations for the department. What would your key recommendations, or take-home points, be to ensure that we reach what we need in the medium term for long-duration energy storage and that we achieve what we need by 2050?

**Michael Liebreich:** At this stage, I would be looking to get clarity on that hydrogen architecture question. That would be very helpful, because hydrogen is linked with long-duration storage. There are alternatives, but hydrogen is high up on my ladder because it will almost certainly be either hydrogen or a derivative if we want net-zero long-duration storage.

If we had a strategy on the architecture for hydrogen and a statement that we are going to have some number of terawatt hours of storage, we could go into consultations on the how.

Do we need to say that it is 10 terawatt or 20 terawatt hours, or whatever? I am not sure. People like an absolute number. Previous comments notwithstanding, let us say that we will target 10 terawatt hours by 2040, because we can always stop there or then add more if we need it. That would be a goal with the sort of energy architecture that we are headed for. As I say, if we can pull forward some decisions on hydrogen heating and so on—such as a moratorium on non-safety investment in gas distribution networks—that would be helpful.

**The Chair:** That has been enormously helpful to us. You have been quite passionate about various things and given us your thoughts very clearly. That will help us enormously in our further deliberations. Thank you very much to Michael Liebreich. We have worked you extremely hard in this session.