HOUSE OF LORDS

Select Committee on Science and Technology

Corrected oral evidence: The role of batteries and fuel cells in achieving net zero

Tuesday 20 April 2021

10 am

Watch the meeting

Members present: Lord Patel (The Chair); Baroness Blackwood of North Oxford; Baroness Brown of Cambridge; Viscount Hanworth; Lord Krebs; Baroness Manningham-Buller; Lord Mitchell; Baroness Rock; Lord Sarfraz; Baroness Sheehan; Baroness Walmsley; Baroness Warwick of Undercliffe; Lord Winston.

Evidence Session No. 6 Virtual Proceeding Questions 70 – 80

Witnesses

Professor Patrick Grant, Vesuvius Chair of Materials and Pro-Vice-Chancellor (Research), University of Oxford; Professor Emma Kendrick, Chair of Energy Materials and Professor of Energy Materials, University of Birmingham; Jeff Pratt, Managing Director, UK Battery Industrialisation Centre.

USE OF THE TRANSCRIPT

This is a corrected transcript of evidence taken in public and webcast on www.parliamentlive.tv.

Examination of Witnesses

Professor Patrick Grant, Professor Emma Kendrick and Jeff Pratt.

The Chair: Good morning, everybody. I am delighted to see you all, particularly our three witnesses, Professor Grant, Professor Kendrick, and Mr Pratt. Thank you, all three of you, for coming today to help us with our inquiries. We appreciate very much your making time. My time is short and we have a lot of questions for you, so I have asked the members of the committee to be sharp with their questions. If you do not mind being sharp with your answers, we might get through them all. Witnesses, when you speak for the first time, can you say your name and whom you represent, to get it on the record?

Q70 **Lord Winston**: Can I thank you, Jeff Pratt, for the excellent written information you have already supplied to us? That has been very useful. Maybe I could start with you and ask you about the stages of development of battery technologies, from the lab stage right through to manufacture.

Jeff Pratt: Good morning. I am the managing director of the UK Battery Industrialisation Centre. Briefly, my experience is automotive. I was 31 years with Nissan, 20 years of that in the vehicle plant, responsible for paint, trim and chassis processes. In the last 10 years, I was responsible for building a lithium-ion battery plant in Sunderland, which supplies batteries for the Nissan Leaf. I built that from 2010 through to 2012 and then ran that until 2018, when I came to the Midlands to build the industrialisation centre.

To answer your question on the stages from initial research through into large-scale manufacture, you start off in the lab with scientists basically developing the base chemistry. Once that base chemistry is developed, you will then trial that base chemistry on what we call a coin cell. We call it a coin cell because it is about the size of a 10p piece[1]. You are looking to prove that the base chemistry formulation works.

From then, provided that is successful, you move on to what we call pilot productions. This is still in a lab, generally in a commercial R&D lab in a big battery supplier, or it could be in one of the key universities that develop battery technology around the country. They would have a pilot line[2]. You would make slightly bigger cells, for example, what we call 21700 if it is cylindrical—21 millimetres in diameter and 700 millimetres long—or a cell around about A5 size if it is a pouch cell. In doing that, you are looking to see whether you can scale this technology up to the next level, so you use a slightly bigger mixer and produce it on a bigger, industrial format cell. You probably make 10, 20 or 30 of these cells. Then you start what we call cycling these cells. You put them through charge-discharge tests.

---

[1] These coin cells are constructed manually in laboratories.
[2] This pilot phase is also the start of early, limited levels of automated assembly with small scale production equipment.

Moving on to the next stage, when they are manufactured, the people start to change. Instead of the scientists in the labs, you start involving the engineers and technicians to 'fetch the chemistry through'.[3] You are then looking to produce bigger batches of the chemistry. Instead of maybe a 10-litre batch, you are looking at 200-litre or 250-litre batches of chemistry. Here, you are looking to get the repeatability of the process right. You are looking at quality, cost and delivery. Can the chemistry be manufactured repeatably? That is important, because the main issue in battery manufacture is making sure that you have a high 'OK' rate, which means you have low levels of scrap.

To give you an example, 1% of scrap per gigawatt-hour (GWh) of cells manufactured costs about £1.5 million. If you are looking at a 30-gigawatt-hour per year plant, and normally a good plant would run at approx. 2% scrap rates, you are talking about £30 million to £45 million of scrap costs per year, something like that, if you hit your target. If you are producing high levels of scrap, you can easily double that. You start getting into big problems unless the process is repeatable and to a high quality. That is what you are trying to prove in the final stage of manufacture.

Q71 **Lord Winston:** Professor Grant, could you tell us about the role of academia and how far you get into the manufacturing processes with the various stages?

Professor Patrick Grant: I am from Oxford University. I am a professor of material science. In the paradigm that Jeff has described, it is fair to say that most of the university work is very much at the beginning of that process. That is about the discovery of improved chemistries, predominantly but not always for lithium-ion technology, the sort of technology you have in your laptop and your phone. There, the challenge is to come up with new materials that can be combined to push up the performance of the battery.

We should not think only of that as the research that gets done, because there is research on the manufacturing process itself. The description that Jeff gave is really about lithium-ion battery manufacture, where, as I said, it is about new chemistries, but universities are researching opportunities about the manufacturing technology itself. Some types of batteries are emerging that do not necessarily drop into the established way of making things.

We need to differentiate between discovering new chemistries and scaling those up, and looking into the manufacturing process itself, whether that is existing techniques and improving the yield that Jeff described as being so critical, or in fact looking at completely new ways of making batteries, which open up performance that we cannot get from the existing technologies. That new-process technology know-how is much less well represented in universities. It happens in the UK, but it is less common and less easy to fund than work on basic new chemistries.

---

[3] That is, transfer the material production into industrially-sized process engineering methods.

The Chair: Mr Pratt, when you are manufacturing lithium-ion batteries at scale, is there a problem with chemicals and gases with lithium anode?

Jeff Pratt: No, there is not a massive problem with gas at the base chemistries, what I call the 532 and 622 chemistries. As you get towards the more active, higher-nickel, chemistries, you get gassing of the cells. Within the formation and ageing process, you normally have to put in a double degas process, which means that you take the gas out of the cell.

Lord Winston: Are there less poisonous substances than methylpyrrolidone?

Jeff Pratt: There is not a major issue with emissions in battery manufacture. It is quite a clean process, actually. There is no large-scale abatement required in a lithium-ion battery factory, as there is, for example, in a car paint shop.[4]

Q72 **Baroness Warwick of Undercliffe:** Thank you very much indeed for joining us. My question is about addressing the challenges of scaling up the next-generation technologies. We heard in the first session that, globally, lithium-ion batteries are currently providing around 300 gigawatts of energy per year, but we were told that there would need to be a sevenfold increase in this total by 2030 to meet requirements for electric vehicles. Given the Government's announcement this morning, that may increase substantially. Could you first say something about the activity that is already occurring at the different stages of development in the UK? Secondly, what amount of manufacturing will be needed in response to demand and to key government policies?

Professor Emma Kendrick: I am from the University of Birmingham. My background is in new battery technology development, in small start-ups, large internationals and now academia.

Perhaps I can talk about the front end of scale-up, which is from the materials through to the prototypes, and then hand over to Jeff to talk more about the bigger aspects of things.

One of the biggest problems I came across in small start-ups and developing a new technology within the UK was to get from the lab scale to intermediate scale. You need to get to the intermediate scale to have a demonstrator before you can move to the pilot line. In order to do that, you develop materials, normally at gram scale. But to go to the next stage, where you develop electrodes, composites, cells, you need kilograms of materials to process in order to develop them into cells to do the electrochemistry, the testing and the cell performance parameters.

[4] Clarification: The response related to the cell, module, pack production process, which are quite clean processes in terms of emissions. However, electrode manufacture does involve N-methylpyrrolidone (NMP), in the cathode production process. In battery plants, NMP emissions are captured in a carbon bed and either tankered to be recycled off-site, or captured and recycled on-site to be re-used within the process; they are not emitted into the atmosphere. However, a field of battery research is looking into how to replace materials like NMP that are hazardous for handling and usage, with safer and more environmentally-friendly alternatives in future.

Once you have a proof of concept, you go to the pilot plants, which produce an industrial-relevant demonstrator. At that scale, if you have a proof of concept, you have demonstrated it and you have a cell that works, the industries really get behind you to scale that up. There is a bit in the middle, and you need to overcome that hurdle before you can go to full-scale production. In my experience, the materials manufacture is one of the hardest things to do in the UK. We worked with the US and Japan to scale up materials to be able to bring them into the UK to do the electrode development, rather than doing that materials scale-up fully in the UK. To me, that is a big gap. Perhaps Jeff can talk about the larger scale.

Jeff Pratt: I will cover what the UK has set up, from initial research through to scale-up. We already have something called the Faraday battery challenge, which is a £318 million investment by government exactly to support the scale-up of battery technology in the UK. That is made up of three pillars. It is made up of the Faraday Institution, which is managing lots of research projects on battery technology in some of the key universities around the country. I am sure Emma has some projects ongoing that are managed by the Faraday Institution. Then we have the centre pillar, with about £80 million going into collaborative R&D projects on battery technology. Then we have the industrialisation centre, which I manage, a £130 million facility to help push technologies through to market.

With those three pillars together, we can do the initial research, get that research ready through the collaborative R&D projects, and push it to market using the industrialisation centre without companies having to put huge levels of investment in to get started.

We also have the £1 billion that has been announced by the Government, the ATF—the automotive transformation fund. This year they have allocated, I think, £400 million of the £1 billion, but we are hopeful that the rest will come through. That is to get large-scale manufacture into the UK. We are forecasting that, by about 2030, we will need between 80 and 100 gigawatts of battery capacity in the UK to meet demand. Depending on the size of the gigafactories, that is equivalent to three to four gigafactories. That capacity will be developed in the UK or will be imported from Asia or Europe. That is the problem. We really need to get this delivered for the UK.

Q73 **Baroness Warwick of Undercliffe:** That leads me on to a second question. It was quite interesting that Professor Kendrick said that she had to go to the US and Japan for the manufacturing to scale up her concept. You all talked about the difficulty of manufacturing here. I wonder whether you could say something about how we compare with other countries. When we had the evidence from the Faraday battery challenge, they were pretty clear that other countries were starting to overtake us.

Jeff Pratt: Asia has always been ahead of us. I worked in a Japanese company for a long time. It is very clear that Japan, Korea and China are the main areas for battery production globally. They have most of the

R&D capability. We are starting to see some of that transplanting into Europe. Some of the big companies are starting to announce or build gigafactories in Europe, and with that comes the R&D capability. We have a couple of promising leads on getting gigafactories into the UK, but up to now we have had no major announcements. It is key that we get the first couple of gigafactories over the line and into the UK.

Professor Patrick Grant: In the near to medium term, with the establishment of gigafactory capacity in the UK, which is very urgent and we are behind, we are essentially talking about off-the-shelf technology, which is more or less available, at least from a capital equipment point of view, from suppliers, probably all of which are outside the UK. Then there is a need to build up the know-how to operate those plants. That may or may not require substantive R&D, but it certainly requires specialist training and the building up of a supply chain in the UK to supply those gigafactories.

Once that capability is established, it will then provide an opportunity for the research base to engage with that capability. In the near term, it is essentially off-the-shelf technology. Where the R&D comes in is that the processes of optimisation described by my colleagues are extremely expensive, time consuming and surprisingly empirical. There is an opportunity to get the science base to work on having much more ability to predict, understand and optimise faster that new industrial capability. That is the way in which we will need to compete. Just like in semiconductor manufacturing, the people who end up really knowing how this stuff works are the ones who operate the plants. It is absolutely essential that we get that knowledge base starting to be built in the UK around these large gigafactories.

The Chair: Mr Pratt, in a sentence, what do you want the Government to announce when it comes to maintaining UK lead?

Jeff Pratt: Definitely in Asia, and in Europe, Governments are incentivising and getting these countries to start up their gigafactories. I know that you have to do that within rules, but the Government will have to incentivise that in the UK to get the first ones in and running.

Q74 **Baroness Walmsley:** We would like to know what equipment, facilities and skill sets are needed for each stage of scaling up. Are they available at the right scale in the UK? How do we compare to other countries in this regard? I wonder if we could focus on the bit in the middle, which Emma talked about, not just the gram stage but the gram to kilogram stage and the next one, which is Jeff Pratt’s stage. Emma, would you like to start on that, particularly on the skill sets?

Professor Emma Kendrick: The most interesting thing for me about battery research, and I have been in it for a long time, is that it is very multidisciplinary. You bring in skill sets from all aspects of science and engineering. Even in my own group, I have engineers, physicists, chemists, chemical engineers and mechanical engineers. I work with electrical engineers and even mathematicians now. It is truly multidisciplinary. It is not just one skill set that you need to be encouraging. You need to encourage people to build between the different disciplines to be able to do this type of research and take it forward into production.

As an example, there are health and safety issues with handling materials. Some of the materials we handle for batteries are carcinogenic. You have to process them in a particular way, transfer them in a particular way and enable the interactions to cast them on to an electrode. It takes chemists and a bit of chemical engineering just to design the processes around what you are trying to do.

Baroness Walmsley: What do we have to do in this country to make it easier for people to work in those cross-disciplinary groups? Has it been harder during the pandemic, or have we learned any smarter ways of working that we can take forward?

Professor Emma Kendrick: The Faraday challenge, Innovate UK and the Faraday Institution have been very useful. They have really encouraged engagement outside your normal field. We have started to engage outside what in the UK was originally very much materials discovery work, which the UK is absolutely excellent at. We now need to get from those brilliant, novel materials into actually demonstrating them in cells. That is where we need the interactions and interdisciplinary work.

The pandemic has been hard. We have obviously spent a lot of our time on Zoom meetings like this, trying to discuss the ins and outs of practical work without actually being able to get into the labs to do some of that. I have been very encouraged by the way the communities have engaged together. I work with engineers of all sorts, as do a lot of my colleagues, like Patrick. That has been very positive over the last few years.

Baroness Walmsley: Mr Pratt, could you talk to us about your stage of the process and tell us what specific equipment and services the UK BIC facility provides?

Jeff Pratt: It is probably worth covering the different skills you need in the battery industry compared to standard industry. In the vehicle manufacturing facility for automotive, I would probably guess that the ratio was about 75% non-skilled staff to about 25% skilled staff. In a battery facility, it is about 50:50; there is a much higher ratio of skilled staff for every unit made.

On the skills, we have production operators, technicians, including maintenance technicians, engineers, QA staff, health and safety staff, so everything you would see in normal industry, just a higher ratio of skilled people.

In a battery manufacturing facility, you still have a lab. You still have scientists in the lab, but the operation is slightly different. They are checking incoming materials to make sure that they are good and at the specification. They are taking cells out, midway through the process, and stripping those cells down to make sure that they are good.

One of the big issues with cell manufacture is that you cannot test a cell to make sure that it is good at the end of the process. You know right on that day whether it is good, but these have to last eight to 10 years in the field. The only way to do that is to cycle test them. That cycle testing takes nine months. All these cells are out in the field, before you know whether they are going to be good, so it is really important that you follow process and get the process right.

In the battery industrialisation centre itself, we have the full suite of manufacturing technologies. It is probably worth saying that the equipment we have is not lab equipment. It is industrial-rate equipment. It is exactly the same equipment as you would see in a gigafactory anywhere in the world. We just have one of each, so we do not have multiple lines; we have one type of technology. We have electrode manufacturing, which consists of mixing, coating, drying, calendering and then slitting. That gets you a finished electrode, ready for cell assembly.

We have two formats of cell assembly process in UKBIC: a cylindrical cell assembly process and a pouch cell assembly process. The third format is prismatic. We do not have that, because we had to go with the ones we thought would be the most prevalent in the market with the money we had. Then we have formation and ageing, which is where you start the chemistry off to optimise the cell performance. Then we have module assembly, and pack assembly, which gets you the finished battery for use in vehicles and other applications. We have the full suite of technologies at manufacturing rates.

Baroness Walmsley: I understand that some of the skill sets for mass manufacturing have come from other industries, such as pharmaceuticals or packaging. Is there a strategy for transferring the knowledge and skills from those industries into the battery industry?

Jeff Pratt: When I started the facility up in Sunderland, and the same again with this facility in the Midlands, I took a few experts in battery technology, but the rest came from general industry and were cross-trained. As an example, you need welding expertise. You need assembly expertise. Yes, there is some process and chemistry stuff at the start, but you still need the other skills. They are as important at later stages of the process. You start off with some base skills and then train them up. As an example, in the Midlands we started with nothing and we now have close to 90 people with battery skills.

Baroness Walmsley: That cross-training is done in industry.

Jeff Pratt: It is. One of the remits of the industrialisation centre is to provide that training for manufacturing going forward. We are busy developing training courses at every stage of the manufacturing process at the moment.

Baroness Brown of Cambridge: I have a quick request of all our witnesses. Professor Grant flagged up that it is quite difficult to get support for research on new process technology. Professor Kendrick flagged up that we have a gap in materials scale-up. As you answer my colleagues' questions, I do not want to cut across their questions, so could you focus also on telling us where there are gaps in funding and capability that we need to be doing something about? Those are areas that we are particularly interested in.

The Chair: That is a good point. Please try to answer that if you can.

Q75 **Baroness Sheehan:** My series of questions focus on the gram to kilogram scale. How much activity is currently occurring at that scale in the UK? What are the specific challenges facing the scale-up of batteries on that scale?

Professor Patrick Grant: We have a real challenge in this area. There is a lot of work in universities at the gram level. I work on manufacturing, and in my work I cannot use gram levels of material; I need kilograms of material for my research. I cannot normally get those in the UK from commercial suppliers, partly because I tend to want to work on fairly up-to-date materials in my manufacturing research. The supply chain does not exist in the UK for that. For example, I work on sold state batteries. I cannot source the solid-state electrolytes in the kilogram scale I need in the UK, so I buy them from America. For my work on high-energy density cathodes, I cannot get the NMC materials from any UK supplier. I have to buy those from China.

There is a disconnect between the fantastic work on materials synthesis and discovery going on at the gram scale, and the ability to feed that into programmes that look at how to get the best out of those materials. I would not want the committee to have the idea that, in manufacturing, one size fits all and that we can put any material into this manufacturing process. The manufacturing process itself needs research, and that research can only be taken forward using kilogram scales of material. We have no access to development materials at that scale in the UK.

For many of the up-to-date materials I source from overseas for my research, I have non-disclosure agreements imposed on me, which means that I cannot publish the results. That is a huge disincentive and precludes me from working on some of the most up-to-date, industrially relevant materials that I would like to operate in my research.

Finally, if I want to build a new machine to take a new approach to building a better battery, it is extremely hard to get capital equipment funded. It is seen as too risky and expensive. It is much easier for me to get funding to buy a piece of equipment from Korea, Japan or Germany. If I have a bright idea to try to build a prototype piece of equipment in my own laboratory, it is extremely difficult to get funding for that type of research.

Baroness Sheehan: What is the potential within the UK to source the materials that you are currently having to bring in from the US and China?

Professor Patrick Grant: It is chicken and egg. The commercial suppliers do not want to invest in the technology to produce kilogram and upward scale until they know that there is a commercial market. They will do that only if they can get third-party funding to help to defray the cost. That is a role for government. As you have heard already, we do not have a gigafactory in the UK. I am very optimistic that, as it is inevitable that we must have such a capability, we will stimulate a domestic supply chain that will incentivise materials companies in the UK to invest in making those kilogram-and-upward scales of materials. That will, in turn, have a trickle-down effect to the science base, allowing us to have access to more up-to-date materials and to collaborate more effectively and speedily with companies in the UK.

Baroness Sheehan: Correct me if I am wrong. I am hearing that, if the political will were there, or if incentives at the level you need were there, we could fill that gap within the UK.

Professor Patrick Grant: We have many of the right things. The Faraday battery challenge has been a fantastic step forward. It was a coming together of industry and academia to highlight these gaps. We have made a very good start, but this is an absolutely cut-throat, intense, international competition. All the things we are talking about are not a secret. These debates are happening in every country about connecting the science base and establishing a sovereign manufacturing capability.

If we want to be anywhere near the leadership of that, which we are definitely not at the moment, we need to double down our efforts. This is not a cheap business. We can be smart, and we have the capabilities and the people to be very smart, but in the end this is a capital-intensive business. It is a strategic issue for the UK and it needs further government stimulus and intervention.

Q76 **Baroness Sheehan:** Professor Kendrick, may I ask you the same questions? Could you also address to what extent researchers working in the early stages of battery development take into consideration the requirements for scale-up and large-scale manufacture?

Professor Emma Kendrick: I support everything that Patrick just said. I have been on the other end of it, from an industry point of view as well, trying to get to a point where I can get my management to invest in the development we have done. I also worked for a large Japanese company in the UK for R&D. There were three things there that could be highlighted. One is materials supply and the materials supply chain. A lot of the batteries use critical materials, which have a scarcity of supply, are difficult to handle or are strategically very important.

Lithium, cobalt and graphite, all of which are contained in batteries, are on the critical materials list for Europe. A security of supply of materials is very important, as is manufacturing of materials in the UK at a scale where we can start the development work or the research into the actual cell development. Patrick talked about manufacturing. To give you an example, for me to get my senior management to agree to invest in the next six months—we had to pitch every six months—I had to produce demonstrators, with testing, to prove that the technology we were developing was going to be worth investing in and we were going to make some money from it.

To do that, I needed to produce industrially relevant cells, and these are similar to what you would produce on a pilot line, so they would be oneamp power cylindrical or stack cells. I needed three kilograms to produce 30 cells to do that demonstration. That is where I needed to go outside. To me, that is the bit that we need to bridge here in the UK.

The issue with going from gram scale to kilograms—again, I have done that myself—is health and safety. You can handle small grams of materials very easily. You do not get exposure. Once you start handling larger and larger batches of materials, there are exposure limits that you have to consider. You have to change your protocols every time you go to the next scale. Even going from a 10-gram scale to a kilogram scale, you need to put a lot more health and safety protocols in place to control any exposure to carcinogens, NMP or whatever process you may do. That is a lot of cost, investment and know-how, and it is not necessarily something the academic community understands well enough. We should also address that.

The Chair: To go back to Baroness Brown's question, the gap is in the availability of kilogram-level material. Is that right?

Professor Emma Kendrick: Yes, and security and supply of the raw materials coming through.

Baroness Sheehan: Do you want to say a few words about the extent to which researchers working in the early stages of battery development take into consideration requirements for scale-up?

Professor Emma Kendrick: Health and safety has a big part to play in this. That is not necessarily considered when you go from a gram scale to 100 grams, to 500 grams, to kilograms, to tonnes. From an academic point of view, we do not necessarily think that far ahead. In some of the work that is being done, including by the Faraday challenge, we are starting to look at how to develop and manufacture materials more at scale. In my lab, for example, we make up to about 100 grams or 200 grams of material. To go larger scale than that, we would need more equipment and infrastructure. As Patrick said, equipment cost is a difficulty where we are, at university level.

Q77 **Lord Sarfraz:** Mr Pratt, other than the automotive industry, which sectors will drive the scale-up of battery technology in the UK? We have heard that there are various funding gaps at different stages of development. Whom should we be trying to incentivise and attract to fill them? Will these be financial investors or investors from industry?

Jeff Pratt: To the first part of your question, the major industry initially will be automotive, as you have already said. It will have a large requirement early on. An industry that could have an equally large requirement is stationary storage, so grid storage, commercial storage and domestic storage. That is seen, certainly by the industrial strategy guys, as eventually being as big a market as automotive.

As electrification takes hold, other sectors will come in. You will have aerospace, rail and marine starting to also electrify as time goes on. Certainly that will be an area of interest for Faraday battery challenge in future, providing funding gets approved in the next spending review. What was the second part of the question, sorry?

Lord Sarfraz: Should we be targeting industry or financial investors? How much do these gigafactories cost? Are these $5 billion to $10 billion projects? With all these reports of various gigafactories being established across Europe, is there any risk of having too many of them?

Jeff Pratt: A gigafactory is a factory of around about 30 gigawatt hours to 50 gigawatt hours per year (GWh/yr) capacity. That is pretty standard for a gigafactory. A 30GWh/yr gigafactory is about £2.5 billion. That is the capital cost for the equipment, the building, et cetera.

The investors for these factories tend to be the established battery companies. They will try to raise finance for it. There are also some start-up companies that are looking to gain investment to set up factories. It is a growing market, so it is reasonable to say that they are all looking for incentivisation. They are looking across the different countries and seeing where they can get the best deal to set up their facilities.

One point I will make, which was echoed by the two professors earlier, is that manufacturing batteries in the gigafactory is about 20% of the cost of the battery. The other 80% of the value is in the materials supply chain. You need the automotive industry initially to be the draw for the gigafactory, but once you have the gigafactory you need to follow on and get the supply chain into the UK to maximise the value. Currently, there is no established supply chain in the UK. As an example, for the two cells I have developed to run through UKBIC, we have had to go outside of the UK for the powders as well. You cannot get them from within the UK.

Lord Sarfraz: Your organisation works with all stakeholders. Have you found that domestic banks have the appetite to fund these gigafactory projects? What is the British Business Bank doing?

Jeff Pratt: The feedback I have had, certainly talking to some companies, is that in the UK the institutions tend to want a quick return on investment. You do not get a quick return on investment with battery manufacture. From spade in the ground to getting the first phase up and running, you are talking two years. You are probably talking at least another two or three years before you start turning a profit.

Q78 **Baroness Rock:** Could I ask the witnesses to have a crystal ball and look into the future? What innovations are there to be made in battery engineering? If you were looking at manufacturing innovations, what would you expect in the next 15, 20 or 25 years? Professor Grant, given that you lead the Faraday Institution on the Nextrode project, where do you think the developing of machines and processes will go? What support do you need for the long-term future—we have talked a lot about the short term—of this area?

Professor Patrick Grant: The way we make batteries at the moment is very empirical. A big change in the medium term will be a much greater predictive capability and turning this from a black art practised by a few specialist practitioners into something that can be design led. We will be designing batteries, rather than optimising batteries. We are very well placed in the UK to do that.

Another innovation we will see is the advent of the solid-state battery—the liquid electrolyte is replaced by a solid material. This opens up a step change in performance, but no one really knows how to make a solid-state battery. There are elements of it that we will make the same way as the lithium-ion battery, but there are some things that do not really work for a solid-state battery, or may not work. We are not quite sure yet. There is a huge opportunity in who can come to market with a really scalable, cost-effective way of making solid-state batteries.

I think we will also see a move towards a more sustainable industry, in particular the advent of dry processing. At the moment, manufacture of lithium-ion batteries is a very solvent-intensive process. It is not very obvious what that means. Basically, we use a lot of toxic, flammable, expensive chemicals in the chemistry and manufacture of the battery. There are moves already by some companies to get rid of that. That reduces cost and improves safety, but it also allows us to make better batteries.

I think we will see a diversification in the type of batteries. Most things are dominated by lithium ion at the moment. The problem that other technologies are finding is that the price of lithium ion is continuing to drop. Every business plan that gets put together to look at a new chemistry is undermined by the fact that the target is moving all the time. None the less, I am optimistic that other types of opportunity will come along, particularly as we move towards grid-scale storage.

I think we will see a new family of manufacturing processes designed for grid-scale storage performance, where per unit weight performance is not so important, because the battery will not be moving around. These will have to be simple processes, because the amount of battery required will be huge for grid scale. We are going to need cheap, possibly even more scalable processes. Some very smart thinking is already going on, particularly in the US. There are lots of start-ups in that area, not all of which are successful, but I think that will lead to a whole new family of technologies coming in the medium to long term.

Baroness Rock: Mr Pratt, I do not know if you have anything else to add. I would also be interested if any of the witnesses have any comments on who is leading the charge on innovation.

Jeff Pratt: I have a couple of comments to add. I agree with Professor Grant. The major chemistry at the moment is the lithium chemistry. Most of the major companies are looking at an NMC-type[5] chemistry. In the medium term, that will go to even higher nickel concentration. Companies will be reducing cobalt and the precious metals in the chemistry. The major driver for that is to get the cost down. The margins are not very big in the industry and automotive demand has even tighter margins. The drive will be to get the cost down.

---

[5] Nickel Manganese Cobalt

Probably around 2027 solid state will be emerging and may be ready. That will be a big step change. All the manufacturers are looking at all parts of the process to get the costs down. They are looking at the manufacturing process and the energy used in it. Throughout the manufacturing process, you have a lot of air-handling for the clean and dry rooms. It takes a lot of energy to put the air through the clean rooms[6] and to keep the air very dry.[7] They are looking at reducing the size of the clean and dry rooms, or maybe only having the clean and dry area inside the actual machine itself.

Instead of drying at the start of the process where they produce the electrode, and then keeping it dry, they are looking to dry right at the end, just before they put the electrolyte in. That takes away the requirement for much of the energy intensive dry area. There are all sorts of things being studied at the moment to try to reduce the cost. Another area is digital innovation and artificial intelligence to make a breakthrough to get the OK rate up and the scrap rates down. Every element of the manufacturing process is being looked at to get the cost down.

Baroness Rock: Professor Kendrick, outside the UK, Tesla is working on innovations in manufacturing. Who is driving this in the UK? Can we be at the forefront of this innovation?

Professor Emma Kendrick: We have car manufacturers in the UK that have an interest in next-generation technologies. I would not say they were necessarily driving that forward in the UK. They are taking innovations from China and Korea that are coming through and are already at demonstrator level, so they can put those into packs and modules and then test them in their vehicles.

A lot of the innovation comes from our research base. We have a really great research base here in the UK, not just with the universities but with the technology developers. We have several small companies that are doing new technology development here. They need support as well to get to the prototype stage that you need to get the next stage of investment for. I can say that investment to the next stage is remarkably difficult, having been through that myself.

I would like to talk about the innovations, though, because in manufacturing and engineering there are huge numbers of innovations that we can make: basic control and feedback for manufacturing; new metrology measurements, and characterisation and control for that manufacturing process; bringing in automation and robotics; and what happens to scrap and the batteries at the end of life. Do we recycle? Do we remanufacture? Is there a second life?

There is partnering between models and manufacturing, whether that be data-driven models with AI, as Jeff mentioned, or physics-based models. There are huge innovations there, bringing in physics-based models to partner with manufacturing. That is another research gap that has not

[6] To reduce contamination of the electrode materials
[7] For moisture sensitive materials like nickel

necessarily been addressed. Another is the integration of sensors into the manufacturing processes but also the batteries. There are huge amounts of innovation that can be done within the UK.

Q79 **The Chair:** My question is very short. After that, I will move on to Baroness Brown, who will frame her gaps question with an actual question, so you can all say where the gaps are. That is what we need to find out.

Mr Pratt, you alluded to the fact that the next technology will probably be solid state when it comes to manufacturing at scale beyond lithium ion. Are any other technologies likely to come to the fore by, say, 2050, or before, which could be manufactured at scale, apart from solid state?

Jeff Pratt: Yes, there are. There are lots of other chemistries. There is sodium ion, lithium sulphur and lithium air, just to name a few. Lots of other chemistries are being studied. Some may be more appropriate for other sectors, such as aerospace. Some of them still have problems such as how to scale up manufacturing processes, so some of them are still in the lab. As you cycle and test the chemistry, the performance degrades, so they are not quite there yet. Lots of chemistries are being looked at, as well as lithium-ion chemistries, for potential use in the future.

The Chair: Where do you think the UK will end up leading on batteries?

Jeff Pratt: There is some good work going on in sodium ion in the labs at the moment. Potentially, we have the ability to be a leader in sodium ion. Solid state is still up for grabs. There are some UK companies, as well as some European and Asian companies, looking at solid state. There is a bit of a race on at the moment as to whose solid-state technology pulls through and becomes the dominant technology. That is still up for grabs at the moment.

The Chair: From the answers I have heard so far from all three of you, it looks as if we are being beaten by everybody.

Jeff Pratt: In the initial research in the universities and labs, we are pretty good. That is my honest opinion. That innovation and the funding of it needs to continue. We are behind on the manufacturing side. There is massive manufacturing in Asia now, and manufacturing is being announced for Europe. We are slightly ahead with the likes of Faraday and UK BIC. There are countries following that model as an example. Germany has announced a facility very similar to UKBIC, taking that as a model, and it is two years behind us. It is substantially more investment than the UK has put in. It is about €500 million. We have a bit of a steal in some areas.

The Chair: If I were to ask you the same question I asked before—what is required to incentivise battery production?—what would it be?

Jeff Pratt: It takes significant investment to support large-scale manufacture in the UK. By significant, I mean that, for the first two or three, we are talking well over £1 billion in incentivisation, if you look at the manufacturing and the supply chain coming to the UK.

The Chair: Which government department do you talk to, or do you not?

Jeff Pratt: We are linked into BEIS and DIT for this.

The Chair: What response do you get?

Jeff Pratt: We have a good response. The Government have announced the £1 billion investment. It needs to go further, because there are opportunities on the table for not one gigafactory but maybe two or three, which we need to get over the line.

Q80 **Baroness Brown of Cambridge:** I am particularly interested in what you see as the gaps. Both Professor Kendrick and Professor Grant have made a very strong case for the materials supply and that opportunity for scale-up. Professor Kendrick, I think you commented on the lack of facilities for prototype development, which perhaps has a different regime from that which you might find in a normal university lab. Could those be generic facilities?

Professor Grant raised the funding for process improvement research. I wondered whether there were any other gaps on that academic to scale-up interface. Do you have thoughts about what mechanisms might fill those gaps? A battery catapult, for example, might be able to provide those kinds of prototype development facilities, or work with companies to help them to get scale-up material. Would that help? What are your thoughts about the gaps and what would help?

Professor Emma Kendrick: We have a catapult for battery manufacturing. The issue there is probably capacity, rather than not having one. We have a lot of small companies and academics trying to build these prototypes, and one or possibly two facilities in the UK that can help with prototyping, which are working at capacity. The advanced manufacturing catapult is also working in this space, not yet on the materials manufacturing but with the coating, mixing and formulation work. There is some work there. It just needs to be expanded upon. The other gap I would like to mention is recycling and materials at end of life, and what happens to them from a scrap point of view.

Professor Patrick Grant: In the US, there are toll manufacturing capabilities run by national government, for example at Argonne National Laboratory, where you can get kilogram amounts of prototype material made. As Emma has said, we have some prototyping facilities here. One issue is access. They are very expensive to access. I do not think they are particularly well set up for university researchers' access and the way they would fund that next scale of activity by getting access to that. More or less the same is true for small companies. The catapult model works extremely well for larger companies. I am not sure it works very well for university innovators, inventors and small companies.

We know we have a gap in this country. The Faraday battery challenge and the Faraday Institution were put together to answer that. The problem we have now is a lack of stability. We have had a series of one-year comprehensive spending review settlements, which is putting a cloud of uncertainty over the funding. In my own research, I cannot guarantee the contracts of my researchers for more than 12 months at a time, which means that I cannot always get the best researchers. The same is true for the availability of PhD funding. Stability would be incredibly welcome, not necessarily more resources. This is a long-term, sovereign problem that needs a long-term commitment from government, not being buffeted by the ups and downs of the current uncertain budgeting process.

Finally, we need schemes that incentivise researchers to work on manufacturing. There is no shortage of people working on chemistry. The library shelves are heaving with new chemistries for batteries, but actually current batteries are rather similar to the ones that were invented in the 1980s. That is because, in some part, the manufacturing is not seen as an integral part of research for better batteries. We need schemes that incentivise that.

Baroness Brown of Cambridge: Are we suffering from the fact, to some extent, that we do not have some of the real mass-market automotive manufacturers in UK companies? Would it perhaps be better, in terms of what we want to be best at in the UK, to focus for example on batteries for more electric aircraft, where we have one of the globally leading aircraft propulsion companies?

Professor Patrick Grant: I do not think it is either/or. The very short-term needs of the automotive industry and the Government's binding commitment to emission targets mean that that needs to be the short-term focus. You are absolutely right: without a big manufacturing capability and associated supply chain, it will be very difficult to keep doing world-class research. It is the manufacturers that have all the know-how and provide all the pull through. The sooner that happens, the better.

Aerospace and grid-scale storage represent really good medium-term opportunities, but I do not think we can wait for them to mature when we have a near-term opportunity, if we all pull together, to really sort out the automotive supply side.

The Chair: Mr Pratt, in a sentence, why are we not talking about batteries that are recyclable?

Jeff Pratt: We are. We are looking at batteries that are recyclable. There are two levels of recycling. First, when the battery finishes its primary use, it is stripped down and the good modules are used in a secondary use, such as stationary storage. A car battery can be stripped down when it has 80% of its state of charge left and can be used in a stationary storage application, because you are not bothered about the power to weight ratio. Once it has finished its final life, there are studies ongoing at the moment about stripping back—

The Chair: Could an industry be built around recycling batteries?

Jeff Pratt: Yes, absolutely. It is one of the studies going on at the moment. We are trying to get this to be circular, so at the end of life the materials we use are recycled back to the constituent parts and used in a process again.

The Chair: I am sorry, but we have run out of time. In fact, we have exceeded our time. Can I thank all three of you most enormously for making time today to talk to us? It has been very interesting. As always, time runs out and we still have lots of questions, but thank you very much indeed. On reflection, if you think you might have told us something different or novel, or you want to add to what you said, please feel free to write in. We would appreciate that very much indeed. Thank you and goodbye.