HOUSE OF LORDS

Environment and Climate Change Committee

Corrected oral evidence: Nitrogen

Wednesday 19 March 2025

10.50 am

Watch the meeting

Members present: Baroness Sheehan (The Chair); Lord Ashcombe; Lord Duncan of Springbank; Lord Jay of Ewelme; Lord Krebs; The Earl of Leicester; Lord Mancroft; Lord Rooker; Earl Russell; Lord Trees; Baroness Whitaker.

Evidence Session No. 9 Heard in Public Questions 65 - 71

Witnesses

I: Dr James Kershaw, Scientific Officer, Opportunity Green; Trevor Brown, Executive Director, Ammonia Energy Association; Andrew Hoare, Head of Marine Systems and Green Shipping, Fortescue.

Examination of witnesses

Dr James Kershaw, Trevor Brown and Andrew Hoare.

Q65 **The Chair:** Thank you to our panellists for being with us for today's second session on the efficient use and management of nitrogen. This session will focus on the use of ammonia as a fuel for the shipping industry. Could our panellists briefly introduce themselves?

Andrew Hoare: Good morning, everybody. It is a great pleasure to be here. I did not expect the invitation last week. I lead green shipping at Fortescue, an ASX-listed company in Singapore. Thank you.

Dr James Kershaw: Good morning. Likewise, thank you very much for the invitation. I am the scientific officer at Opportunity Green. As an organisation, we aim to close the gaps in global climate action using law, economics and policy. In my role, I lead our work looking into the challenges and opportunities associated with using ammonia as a shipping fuel.

Trevor Brown: I am the executive director at the Ammonia Energy Association, a global trade association that aims to address the decarbonisation of ammonia production and the adoption of ammonia as a low-carbon molecule in energy applications.

The Chair: Great, thank you very much. What are the sources of nitrogen emissions across the ammonia supply chain and how are these evaluated? That is the entire supply chain from production to combustion.

Trevor Brown: Ammonia is, of course, a commodity today. We produce roughly 200 million tonnes of it, of which roughly 20 million tonnes is traded globally on international waters. The supply chain is well established and understood. Currently, nitrogen emissions are largely an end-use agricultural sector, where reactive nitrogen is applied directly to the soil. Very good work analysing this has been done by the International Fertilizer Association, IFA. I refer you to its 2022 report *Reducing Emissions from Fertilizer Use*, which outlines a 70% possible reduction in global reactive nitrogen losses in that sector by 2050.

On future uses of ammonia as a fuel and energy carrier, these aim to be minimised or eliminated through complete combustion in engines or turbines, or complete conversion in fuel cells or crackers, producing as a result inert atmospheric nitrogen, N_2, and water.

In terms of supply chain leakage and incomplete combustion, as we see it, there are three molecules of interest. The first is ammonia itself, which is classified as a toxic gas and has a significant impact on human and environmental health and safety. As a result, any releases of ammonia, whether in the supply chain or at the point of combustion, must be minimised both in frequency and consequence. Ammonia is detectable at a very low level, roughly 5 ppm. The smell of ammonia is detectable. Alarm signals will typically be triggered at about 25 ppm, depending on the codes and regulations applying in the jurisdiction we refer to.

Emissions of ammonia will be minimised from the perspective of human health and safety long before they become a significant environmental concern.

The second molecule we are concerned with today is N_2O, nitrous oxide. This is a greenhouse gas with a global warming potential on a 100-year basis of 273, according to the IPCC's *Sixth Assessment Report*. Mitigation of N_2O is well understood. In recent decades we have gone through the almost complete elimination of N_2O emissions in the ammonia-related downstream industry regarding nitric acid production, which used to be a significant contributor to global N_2O emissions. In the European context, we have been able to achieve 95% to 98% abatement results using N_2O catalysts. This technology is now very well understood. The ability to apply it in stationary and mobile sectors is available.

Crucially, N_2O is a greenhouse gas. As we move to adopt ammonia in energy applications from a carbon accounting perspective, N_2O emissions have already been accounted for in those calculations. This is why emissions measurements on a well-to-wake or well-to-wheel full life cycle assessment basis, including not just CO_2 but also CO_2 equivalents, are critical. That has been broadly accepted by all the regulators, so this is not particularly in question. Recent engine tests show N_2O emissions from ammonia-fuelled engines at roughly 3 ppm, so this is a well-addressable concern.

The third species is NOx, which is again a very well-understood pollutant. We are all familiar with NOx as a result of diesel emissions and regular fossil fuel emissions. These also exist in ammonia combustion. It is critical to point out, though, that, while we might talk about adopting ammonia in new applications, these are not new. These are existing applications for fuel usage. There are existing regulations concerning NOx and those limits should not be changed for the adoption of ammonia.

Dr James Kershaw: I will just pick up on a few of the points Trevor made and add a few bits. We completely agree that the main sources of nitrogen pollution from ammonia as a shipping fuel will be the three species that Trevor outlined there: ammonia, NOx—nitrogen oxide—and nitrous oxides.

It is quite helpful to walk through the fuel supply chain. First, we have ammonia production. I flag here that it has been shown in peer-reviewed scientific studies that ammonia production plants are hotspots for ammonia emissions. Not much work has been done in this area but I will note that there is an ongoing study at Princeton University to look into this in more detail, which has just started.

As we move through the supply chain from ammonia production to interim transport and storage, there will inevitably be leaks and spills of ammonia. That is quite uncertain at the moment, but a recent study from 2023 suggested that between 0.3% and 2.5% of supply chain input might be lost throughout those processes.

I will flag a few points from on board vessels. We are perhaps slightly more concerned about the potential impacts of unburned ammonia emissions and ammonia spills and leaks from on board vessels. These can have quite challenging public health and environmental impacts that have been shown to be potentially quite large. From a public health perspective, a recent study from 2024 showed that if we adopt pure ammonia-fuelled engines on board all global vessels—this is an end-member scenario—with today's regulations, that could result in—

The Chair: We have a later question on regulation and policy in this session, so that can be covered there. Would you like to very briefly add anything, Mr Hoare? Then we will move on to the second question.

Andrew Hoare: Thank you. First, to give some context here, we are a large Australian mining group with credentials on ammonia. Just to connect those dots, we are at the forefront of green molecules and electrons, mining critical minerals. We are developing heavy-duty power trains and charging solutions to support energy transition in the UK. We employ more than 1,200 people, principally around Oxford in five locations. We hope to positively contribute to the UK balance of payments in due course.

Our main involvement is to decarbonise our supply chains, and the marine side is particularly difficult. On the land side, we principally do that through electrification. On the marine side, we chose ammonia as the fuel of choice because of its credentials without the carbon molecule. That is where I inherited or took over the project for the "Green Pioneer". I delivered last year in April the world's first ammonia-fuelled, class-approved Singapore-flagged vessel.

The Chair: Thank you. In terms of emissions, your challenge is nitrous oxide.

Andrew Hoare: We have two challenges on nitrogen emissions, which are well known, and it is important that they have surfaced early. For LNG, we think slip has not been discussed early enough, which is why that remains a challenge. Our challenges have been N_2O and NOx. In our projects, these have been managed through both combustion and the selective catalytic reduction or SCR process. We have had very positive results on what I would call a gen-1 project of a 15 year-old vessel. We entirely eliminated our NOx during that "Green Pioneer" project and detected no NOx pollution during assessment of the gases leaving the flue.

For N_2O, as my good colleague Mr Brown mentioned, there have been some very positive results from the engine manufacturers in the last few weeks and I will name the engine manufacturers. We have Wärtsilä, WinGD and MAN. The latest results are from a WinGD project, where it brought the N_2O down to 3 ppm. Ultimately, it achieved that through the combustion process and not through the addition of catalysts. We have seen a very positive approach to addressing these two nitrogen

compounds through combustion rather than using SCR. We are very encouraged by that from a marine perspective as well.

The Chair: Excellent, thank you very much.

Q66 **Lord Trees:** How established is ammonia as a fuel for shipping and how quickly is that industry developing? Perhaps you could tell us why it is an appropriate fuel for shipping.

Andrew Hoare: It will be established very soon. We will see the first infrastructure being developed in Singapore from 2027. Why is the world choosing ammonia as the next fuel for shipping beyond the transition fuels of LNG and biofuels? It is simply because of the relative ease of production and the fact that it does not have the carbon molecule. That is why Fortescue will adopt this fuel for its supply chains. We can also see that, in the European context, they are strongly promoting the use of ammonia on smaller vessels to decarbonise the Norwegian continental shelf. Principally, that is our main drive for using this fuel and not to use those fuels that can only partially reduce the amount of CO_2 to the atmosphere. LNG, we know, only does that by 25%. Biofuel has other challenges and is probably likely to go up to planes rather than to ships. Shipping has got used to paying for the bottom-of-the-barrel fuel for many years and it will always be highly price-sensitive by the nature of the way freight mechanisms work. We believe that this is where ammonia has a place.

Lord Trees: What increase in ammonia production is expected from these applications in the UK? Globally, how might that affect fertiliser prices in general?

Andrew Hoare: I will leave my colleagues to relate that to fertiliser pricing. Of course, it will be priced principally around European blue ammonia prices in the early days. Today, the bunkering market is a business of about $130 billion. We expect the adoption of ammonia to rise to about 1 million tonnes by 2030 globally and then quite rapidly increase. Of course, the driver for that in Europe is FuelEU in particular. We hope from the IMO—I am looking over to my left there—to see some bold decisions made in April, where the structures and framework are set for midterm measures on a global fuel standard. If we can see bold action there during the next few months or certainly in April, we believe that the acceleration of adoption will be much faster.

Lord Duncan of Springbank: Has the inclusion of shipping within the EU ETS been a principal driver of the change happening and anticipating that within the UK ETS due soon?

Andrew Hoare: I may not be best qualified to answer that question. We can revert back to you on that point. It is a good question. Thank you very much.

Lord Duncan of Springbank: That is fine. I am happy to have it in a written response.

Lord Krebs: I address this question to Andrew in the first instance. Looking at a recent Royal Society report on the uses of ammonia in a net zero economy, there are a number of competing uses: transportation, energy storage, heating and cooling, and other uses. Could you tell us either now or in writing about the merit order for the use of ammonia in these different sectors?

Andrew Hoare: I believe that all ammonia that will feed into the maritime sector will come from new projects. They will be principally green and perhaps blue projects, so I do not see necessarily that they will compete directly with the fertiliser sector, which will draw from existing projects that will likely transition. In our own group, we are looking for supply for our Holmaneset project in Norway and projects in Pecém in Brazil, and in Oman. Likewise, we can see other projects within the Asia-Pacific region, including in India and Australia, serving shipping needs. The first most likely offtakes, particularly in the Asia-Pacific region, would appear to come from the maritime sector in Singapore. They project that roughly 50% of the demand will be for shipping and 50% will be for co-feed into the existing Singapore power network.

Dr James Kershaw: I will just comment from my side on how much ammonia will be required for the shipping industry. If you take the 2018 shipping industry and say, "How much energy did it use globally?", and, "How much ammonia would you need to meet that energy demand?", it is something like 710 teragrams of ammonia, which is about four times as much ammonia as is currently produced. The amounts are substantial. Most projections do not suggest the entire industry will use ammonia. The IEA says that something like 44% of ships will use ammonia by 2050. The UK CCC foresees 22% of UK shipping energy demand being met by ammonia by 2040. Even so, we are still talking about big numbers. I just wanted to give some context on that. The green hydrogen that will be needed to produce this green ammonia also has a range of uses and is earmarked for the decarbonisation of a range of industries and processes. There has to be a discussion about how that need is met and how that resource is distributed too.

Trevor Brown: I will address the first question about how quickly the industry is developing, with some data points. There are now 130 ammonia-fuelled vessels ordered or announced, and 225 vessels ordered or announced that are ammonia-ready, meaning that they could be converted to use ammonia fuel in the near term. Of the operational vessels that we have today, in addition to the Fortescue vessel that we heard about, there are some other small-scale supply vessels in operation in Tokyo Bay, for example. Of the 58 ammonia-fuelled vessels that have been ordered, 27 are ammonia carriers and 27 are bulk carriers. These are vessels focused on large-scale, long-distance transportation of bulk commodities. This goes to the question of why ammonia is an appropriate fuel in this sector. We are talking about very large-scale, long-distance transportation of freight where electrification simply is not a viable option. A decarbonised molecule will be required in the shipping sector.

On the question about the EU ETS as a driver, the broader IMO regulations that we expect to hear about in the coming month will be a broader driver than that. We have not yet seen drivers moving to the commercial adoption of ammonia. That will come in the next couple of years—2026 and 2027—when more of these vessels hit the water and use ammonia as a fuel.

The question regarding merit order is important. There is no single answer. There are significant regional differences and market requirements. In Japan and South Korea, which are energy-importing countries, those Governments propose to import ammonia as a fuel for power generation and for cracking to provide hydrogen supply on a domestic basis. That is importing ammonia for use in domestic markets. We are not likely to see such use cases in the UK necessarily, where we are more likely to develop a domestic production base. The merit order might be different from one country to another and it is important that we keep that in focus. There will be no good solution for transcontinental freight in the shipping sector other than decarbonised molecules. The other key here is to look at what the viable alternatives are in each sector.

The Earl of Leicester: My question is for Mr Hoare. We have read that your ship, the "Green Pioneer", can be fuelled by both ammonia and diesel. Presumably, a specific internal combustion engine has been developed to do this; we cannot just grab all other ships with diesel engines and convert them to take ammonia.

Andrew Hoare: Our ship was traditionally a diesel or gas-oil fuelled one that we then converted to run on either ammonia or dual-fuel ammonia and diesel. All vessels at this time use a pilot fuel in the process. A modern brand-new ship or new-build engine will run roughly 95% on ammonia and 5% on diesel. My ship is a 15 year-old vessel, so those numbers are a little bit different. She is a conversion vessel. The market opportunity going forward is both the newbuilding market and the conversion market. We have shown that you can convert a four-stroke engine.

The Earl of Leicester: The capital cost of conversion is not particularly high.

Andrew Hoare: The capital conversion cost will depend on the type of vessel. I am reluctant to give out numbers today, but we can write to you on that.

The Earl of Leicester: It is cheaper than building a new ship.

Andrew Hoare: It would be cheaper than building a new ship.

Q67 **The Chair:** What are the panel's views on the impact on fertiliser prices if demand for ammonia goes up substantially? Trevor Brown is nodding. Please do say something on that.

Trevor Brown: Certainly. We talked about different potential demand scenarios for ammonia in the maritime sector. All the numbers that the other panellists mentioned are significantly larger than today's fertiliser market. As we think about the impact of scale and liquidity on the price of ammonia, we are moving beyond a scenario where scarcity and competition between molecules creates, necessarily, price increases for food and into a situation where we globalise a commodity greater than it is and increase production in areas that currently do not have significant food security.

As we look to developments around the world—I think specifically of countries such as Angola or Brazil that have very large ammonia projects under development—they are anchoring those in domestic fertiliser markets, taking off a small amount of the output but de-risking the investments in the export market, providing maritime fuel and ammonia for other export markets. As you look at the sector coupling between fertiliser and maritime fuel or hydrogen exports, there is a very positive relationship there that we can keep focused on to ensure that we avoid these risks.

Lastly, on initial adoption, the agricultural sector is not decarbonising rapidly. The market demand for maritime ammonia is solely for low-emission molecules. There are two separate products here. They have the same molecule but one is a low-carbon molecule and one is not, and they have separate markets and separate pricing.

The Chair: Thank you. Dr Kershaw, do you want to add to that?

Dr James Kershaw: To be honest, I have no further knowledge of the impact on fertiliser prices.

Q68 **Lord Rooker:** How involved are the UK Government in international developments to establish ammonia as a fuel for shipping and decarbonising the shipping sector more widely? Mr Hoare, I was not clear about your point. I know that a diesel engine, an internal combustion engine, can be converted to run on hydrogen. I have seen them at JCB. When you talked about conversions, do you mean a brand-new engine or conversion of the ship? I was not clear.

Andrew Hoare: Conversion of the engine.

Lord Rooker: Conversion of the engine in a similar way.

Andrew Hoare: The existing engine with a change in the way the fuel is administered.

Lord Rooker: That is very helpful. How involved are the UK Government, bearing in mind that we can talk to the IMO quite easily, I assume?

Andrew Hoare: First, I should say a significant thank you to the UK Government for allowing us to bring our ship into the UK. In coming here, the UK is only the second jurisdiction to undertake ammonia operations. We engaged very positively with the DfT. We had exemplary support

from the UK Maritime and Coastguard Agency in Southampton. We had the fun choice of then being told, "But you have to find a port to take your ship". We took a train to Portsmouth, which meant that Southampton very quickly confirmed that we could conduct ammonia transfer in its port. We have seen the whole layer of support right down from the IMO, flag state and classification level to the ministry, coastguard and port level. The UK, frankly, was surprisingly open to us bringing this technology to its port.

Having said that, I do not live in the UK so I speak about it from afar, but I come from the UK. It[1] is operating with LNG and other gases in the ports. In Southampton, they are bringing LNG over from Holland to fuel some of the cruise ships and container ships there. It is already quite sophisticated. The interest that the UK expressed in this project has also been very interesting. We hosted the Minister, Mr Kane, last week in Canary Wharf. We have had a number of delegations from the DfT and one from the Department for Business on board the ship. They know that this ammonia fuel is on its way and a very likely contender. They are asking themselves what they need to do. Is it supply, infrastructure or demand? Of course, that is a longer-term question to address. Certainly, most importantly, the ships with ammonia capability or fuelled on ammonia will call at UK ports. One of the main purposes of our global showcase is to make sure that the ports are open and ready. In the case of LNG, it has taken 20 years from the IMO validating the fuel to the fuel being allowed into that port.

Dr James Kershaw: I will just come in on the IMO point. The UK is a key negotiator at the IMO and has a track record of advocating for ambitious climate policy. There are definitely opportunities in future—by that I mean the next couple of weeks—for the UK to play a critical role in advocating for ambitious climate policy. The details of some of those measures that are to be decided at the IMO in its next round of Marine Environment Protection Committee meetings will really determine how effective in many ways the adoption of ammonia as a marine fuel will be for ensuring reductions in greenhouse gas emissions.

In a previous answer, we spoke about well-to-wake emissions accounting. It has actually not been decided yet that that is what the IMO will base its measures on. There is an alternative proposal called an adjusted tank-to-wake proposal. We are really encouraged to see that the UK is advocating for including those production-side emissions in a well-to-wake accounting method. It is really key that we adopt that for ammonia because production-side emissions can be significant, so it is essential that the UK continues to advocate strongly for that.

The details of things like default emission factors that will need to be decided at the IMO are important. We have heard about N_2O emissions. I would counter some of what has been said; these are still really uncertain and I can point you to a wealth of scientific literature that says so. If you

[1] Note by the witness: The UK

adopt a really low default emissions factor, there is no incentive for industry to demonstrate superior performance. You can just use that default value at the low end and that is fine. The UK has a critical role to play at the IMO in the next couple of weeks of really nailing down these details and trying to be as ambitious as possible on some of these climate-related policies.

Lord Rooker: Trevor, do you have anything to add to that?

Trevor Brown: The comment I would add is more on UK policy. The UK has quite a clear view of the role of ammonia in terms of providing hydrogen imports for potential crackers, supporting hydrogen's role in the economy. I am really looking forward to that moment where the policy gets connected between these different sectors and we start looking at the way that all the work going on with coastguards and at ports gets connected with the energy imports, so the maritime fuel policy levers start moving together. Significant synergies can be gained by having a full view of the role of ammonia in the future economy that are not yet captured in policy decisions.

Lord Rooker: I have one supplementary question because it figures in some of our discussions. Is planning permission required at the ports for these ships? Was a planning application required at Southampton, for example?

Andrew Hoare: In Singapore, no, planning permission was not needed because we used existing ammonia infrastructure. It was an existing storage facility operated by Vopak of the Netherlands in a joint venture with Singapore. We used its ports. There is no planning permission as such required if that infrastructure is already there. Of course, in the process, it allocated other areas to build the tanks. Those are in industrial areas, so there would be a certain process there in locating energy products. The existing energy supplier will probably be around the LNG suppliers and so forth in Singapore. There certainly is a planning process of some form. I am sure there is in Teesside and so forth in the UK. I was not privy to that. We supplied data to assist with its plume modelling analysis and those sorts of studies to examine the impacts of, for example, catastrophic events on ammonia-fuelled and ammonia-carrying ships into the region.

Lord Rooker: Dr Kershaw, is planning an issue in terms of the UK?

Dr James Kershaw: Here, I am speaking from the perspective of a previous role, just to be clear. In the UK, to get port infrastructure built, permissions need to be sought from terrestrial planning authorities. You also often need marine licences for anything to be built or constructed or for activities that will occur below UK mean high water springs. Some of it might also go through the nationally significant infrastructure project, or NSIP, framework as well. This speaks to a need for joined-up policy across the different facets of the UK Government. These different systems will need to interact with each other.

Lord Rooker: Okay, that is where we will fail.

The Chair: Thank you. I have a supplementary question related to Lord Rooker's line of questioning. What are the regulatory requirements before a ship fuelled by nitrogen can dock? To whom do you report emissions?

Andrew Hoare: The regulatory requirements, as we can see, follow a similar trajectory in the UK. Ultimate governance is through the IMO. Rules are then applied by a classification that applies to the ship. Those rules are enforced by the flag state. In the case of the "Green Pioneer", it is a Singapore flag. Then it works through ministry level, coastguard level and port level. Each of those seemingly requires its own level of consent.

The Chair: IMO requirements or UK Government requirements?

Andrew Hoare: The IMO sets the guidelines. In the case of the "Green Pioneer", we were instrumental in helping to craft the safety guidelines for the IMO in the IMO MSC. In this case, input also came from the flag state of Singapore and from Japan. It is a collaborative process rather than an imposition.

The Chair: I understand that the clean maritime plan is not up to date. The UK Government's clean maritime plan is still based on the 2018 IMO requirements. Is that something that you are aware of? Is there a sensible recommendation here that we could make from this session?

Dr James Kershaw: I can come in on that. We would say that the clean maritime plan is at this point slightly out of date. It is fair to say that there are recognised problems with the current clean maritime plan. The Government have said they intend to refresh it but we have yet to see that.

The Chair: Thank you. We do not have time to go into what improvements can be made, but if you could write to us with suggestions, we would be very grateful. Thank you. We will move on.

Q69 **Lord Ashcombe:** This question is probably directed at Mr Hoare. I think you have slightly addressed this, but my question goes further than that. How is the shipping industry generally planning to reduce the risk of pollution swapping, with nitrous oxide emissions from ammonia combustion replacing the carbon emissions from fossil fuel combustion? To what extent does it need to be demonstrated that the use of ammonia as a fuel will not substantially increase emissions of nitrous oxide, nitrogen oxides and ammonia into the atmosphere, bearing in mind, as you described earlier, that they are somewhat more polluting than carbon dioxide?

Andrew Hoare: The process will be that the engines that are developed—such as the ones that we mentioned earlier with 3 ppm—are rated engines. That engine then becomes the definitive engine on that ship. That has a certain rating and it is understood therefore that that engine will pollute. Those ratings are then verified or cross-verified by a classification society—for example, Lloyd's or DNV and so forth—through

the life of the ship. Certainly in the case of ammonia, we are constantly regulating or analysing what we put up the chimney of the ship through gas analysers and so forth. Ultimately, the technology has been focused on getting the engine to behave properly, and that is set in the factory settings. It is not something that is amended in due course. On the other side, we monitor to make sure that the engines perform exactly as was stated through the rating of the engine by the manufacturer, and the manufacturer is accountable for that.

Lord Ashcombe: And is it?

Andrew Hoare: In other fuels, across fuel oils and so forth, the experience has probably been mixed. Of course, we do not have that record for ammonia. There is no reason why a manufacturer should not do so and it will be very quickly called out if it does not comply. In a way, we have an advantage; we have very few engine manufacturers globally at this scale—WinGD, MAN, Wärtsilä, and some Japanese ones under licence as well. We have a relatively small number of people to focus on and they know very well that they are under the spotlight, so cannot afford to get this wrong. MAN withdrew one of its LNG engines prior to it being imposed on ships—in fact, it had gone on to some ships—when it was clearly shown to be not quite what it said on the tin. It had to withdraw it or there would have been litigation. It is very aware of its responsibility in describing its engines properly.

Lord Ashcombe: Is 3 ppm the right level?

Andrew Hoare: We all want to approach zero. I think 3 ppm is pretty good. For other nitrogen pollutants or greenhouse gases, we are achieving better levels because of the lower heat of combustion than for diesel. That should not be forgotten. Often, it is comparatively adverse, but ammonia burns with less NOx than diesel.

Dr James Kershaw: This is one of the key things that I wanted to say today. The whole point of adopting ammonia as a marine fuel is to achieve substantial and meaningful greenhouse gas emissions reductions. The key thing to take away is that these are not guaranteed and we need robust, coherent and co-ordinated policy regulation and technical standards to ensure that.

To follow up on a few numbers, in terms of peer-reviewed, publicly available data, at the moment we are limited to lab experiments on small engines and theoretical computer simulations. Those show a really wide spread of potential N_2O emissions, covering more than an order of magnitude. The largest is 50 times larger than the smallest. At the high end of those estimates, we approach the CO_2 emissions that you get from a conventionally fuelled or LNG-fuelled engine, which completely takes away the point of switching to ammonia in the first place.

Andrew is completely right that there are solutions to this. Technical means, engine design means and potentially exhaust gas aftertreatment techniques can help us to bring those N_2O emissions down, but what we

need from industry is for the first movers here to report robust, transparent and publicly available data on this that can be scrutinised. We also need policy things like the default emission factors that I mentioned earlier to be designed in such a way that incentivises industry to demonstrate better performance. It is key that this is not a guaranteed reduction. We need to enable these opportunities.

Lord Ashcombe: What do you consider a suitable sample of vessels floating on the seas to produce the relevant information?

Dr James Kershaw: That is a really good question. There is not a right answer to it. At the moment, we do not have any data from an actual ship that is out sailing with an ammonia engine.

Lord Ashcombe: Not one?

Andrew Hoare: Just on your point there, Dr Kershaw, you are right that some of the tests are being done on single cylinders, but all WinGD, MAN in Copenhagen and one cylinder in and Japan [2]on a full engine are required to run multiple thousands of hours of cycles on those engines as a full maritime engine, albeit on a land-based test bed, before that engine can be put into the ship. You are right that we are of course very keen to advance this quickly, but the timing required to make sure that they go through those stringent tests is non-negotiable. They have to run the requisite land-based cycles on the full engine before it is allowed to be used and rated on the ship.

Dr James Kershaw: Absolutely, but we would like to see those data being robustly reported, publicly available and for that evidence to be incorporated into the currently available evidence base. I can point the committee—we already did in our written submission—to a review of what is currently available, which is what I referred to in my original answer.

Trevor Brown: I want to come back to well-to-wake accounting. This is one of the most important things that we achieve from a regulatory perspective. If this is still in doubt at the IMO, we need to remove that doubt. We need to do carbon accounting on a full life cycle basis, taking into account all the N_2O, in the way that we address decarbonisation of the maritime sector. That is the first critical key.

On emissions, I refer you to a very useful report, *Managing Emissions from Ammonia-Fuelled Vessels*, published in March 2023 by the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. This will provide a broad overview of all the mechanisms by which we can address emissions. It makes the point that this sector has learned from mistakes made during the adoption of LNG, when we set out some decades ago without consideration of things like methane leakage. We are not making those same mistakes today. We are fully aware of the supply chain

[2] Note by witness: one cylinder is in Copenhagen

impacts and of requirements for measuring and reporting these appropriately.

As Dr Kershaw pointed out, this is an existential issue. We will not adopt ammonia as a maritime fuel if it fails to perform a decarbonisation purpose. That market adoption and those engine sales will not exist. The orders for ships to be built will not materialise. The industry knows that this is an existential issue. We are adopting ammonia as a fuel for the purpose of social decarbonisation, to achieve net zero goals by 2050, to support the Paris Agreement and to achieve the IMO's GHG ambitions. This is existential. If we get it wrong, there will be no market and no adoption.

The Chair: That message is heard loud and clear.

Earl Russell: Very briefly, I want to pick up on the exchange between you and Dr James on the issue of data. Congratulations on having one of the first test beds. Do you monitor ammonium on ship? There has been talk of no test beds at sea. Are you prepared to share data with the IMO on emissions? Is there even a system in place for doing that?

Andrew Hoare: We had a land-based test bed in Perth before we moved. Exactly the same engine type was on the same ship. We then shared that data with Class and with the flag state in Singapore. As to the mechanisms for sharing that data more broadly, Class has certain obligations to report that as well. I am not fully clear on those. Ultimately, through our reporting and general shipping requirements, we must submit Class-verified data to various jurisdictions. Up till now, that has been to Europe and so forth rather than towards the IMO. As the IMO adopts these standards, we will have to report to it.

Lord Ashcombe: Are you monitoring internally continued emissions?

Andrew Hoare: Yes, we are. We are not burning green ammonia today. We do ammonia as short tests rather than prolonged usage. The prolonged usage is when we ran for many hundreds of hours on our land-based test bed. Here, we run ammonia to measure those emissions as well as to cater to other safety elements and so forth. There is a much broader element to that project. Yes, we have extensive equipment on board the ship with 32 sophisticated gas analysers and sensors, for both sensing for emergencies and analysing for a much broader spectrum of understanding.

The Chair: Thank you. I am speaking into the ether here but, if the IMO is listening, we would very much welcome evidence from it. Its role in regulating emissions from ammonia as a fuel in shipping will be absolutely crucial and we would like to hear more about that. Before we move on to Baroness Whitaker, could you tell us about the proposed North Atlantic emission control area and what could be its implications for ammonia fuel?

Dr James Kershaw: I am happy to come in on this. The previous Government consulted on potentially expanding the North Sea emissions control area to cover all UK waters. At Opportunity Green, we strongly support that proposal. From the perspective of ammonia in the future, it has been demonstrated that robust policy and regulation are required to avoid potentially severe adverse public health effects and that in adopting things like expanded emission control areas, which will limit NOx emissions, there are ways that those adverse impacts can be avoided and, potentially, public health impacts be achieved. So, quite a simple answer to your question is that we would see it as a positive step.

The Chair: Thank you. I will move on. If the other two witnesses want to add anything to what Dr Kershaw said on that, please write to us.

Q70 **Baroness Whitaker:** Good morning. I should declare that I am a member of the board for the regeneration of Newhaven, where port activities and shipping are a significant element. What you have said so far has been extremely helpful.

What is the general view of green ammonia and what are the associated opportunities and risks? Mr Hoare has already mentioned it a number of times, but I am sure you all have something to say.

Andrew Hoare: As a group, we are promoting green ammonia because we believe that it is the only true way, from a well-to-wake perspective, to decarbonise our own shipping supply chains from Australia to China. We will likely see green ammonia transitioning into the power sector as well. We believe that it probably will be dropped into shipping before other sectors. Our step game is moving from fuel oil to green ammonia without going through any of the intermittent stages of either blue ammonia or other fuels. It is our aspiration and objective to achieve that, and that is what we will produce. We have other leads in the group looking at developing green ammonia for fertiliser, which I am less familiar with. My colleagues behind me know more about that. Our objective throughout is green ammonia for the molecule.

Baroness Whitaker: Is it expensive?

Andrew Hoare: It is expensive, but so too will be the cost of not moving, through either what gets established there or even existing regulation like CII, which will require ships to slow down. When ships slow down in an environment of high newbuild prices, you have less deadweight to carry the tonnes. You will find that costs will creep in, in different ways that are not directly clear. Yes, work has to be done to reduce costs. We know that 50% of the cost of green ammonia is the cost of power, which is why we focus our production in areas where they are probably long in renewable energy such as Norway and Brazil, because they are the only areas where we can get that power price reduced to make it viable. We must also look at the other side. The cost of not moving will also be expensive. That is easy to see when one is in Europe. You can see that the likes of FuelEU have been quite proactive. It is less easy to see today in Asia, where we have not had so many of

those rules or mandates implemented, but we will, because the mandates generate revenue, so people will be quite interested in that.

Trevor Brown: This is a very good question. From a nitrogen perspective, there is absolutely no difference between green ammonia and blue ammonia, or any other colour ammonia. In terms of the pollutants and the molecule species that would result, these molecules are identical.

From a cost perspective, we have just heard an excellent answer from Mr Hoare. Any synthetic molecule will appear expensive relative to unregulated fossil fuels and in a system in which we are not pricing carbon emissions. In a system in which we do value decarbonisation, there are many ways in which the expensiveness of green ammonia can be easily mitigated and spread more appropriately across the value chain.

To avoid price shocks, people talk about it being expensive, but it is expensive only if you ask a farmer to pay double without any guarantee of an offtake. If you effectively spread the cost across the supply chain, these are manageable prices. If you think about the cost of food, we are talking about a couple of pennies or cents on a loaf of bread—not a price that creates terrible shocks across the economy.

There are good prospects for green ammonia. It is an important technology. It has to be where we end up. There is a long-term transition to get there. Next year, our first world-scale green ammonia plant will be operational at Neom in Saudi Arabia, producing 1.2 million tonnes of green ammonia per year. At that point, I believe this narrative about how difficult green ammonia is will shift as we move up the learning curve.

Baroness Whitaker: If you have any quantification of any of these very enticing arguments, please send them in.

Dr James Kershaw: I echo what Trevor said and point out that this potential greenhouse gas emissions pricing is really up for grabs at the IMO in a couple of weeks. There is potential for the IMO to adopt a levy. That is a way in which fuels such as green ammonia can be incentivised, compared with their higher-emitting counterparts and alternatives. By advocating for a high price for greenhouse gas emissions, for example, in two weeks, the UK Government can play a role in that.

Q71 **Lord Krebs:** We have already touched on this to some degree, but I want to ask about the potential environmental and public health risks from using ammonia as a fuel in shipping. Assuming that ammonia is widely adopted as a fuel, in due course there will inevitably be an accident or spill, because that is just the way things are. Ammonia is an extremely toxic and dangerous substance. All of us who have done chemistry know that you handle 0.88 ammonia solution with great care. What precautions would be taken to deal with the impact of a release of ammonia from shipping if it is used as a fuel?

Andrew Hoare: At this juncture I invite all members of the committee to visit the "Green Pioneer" for our next showcase, because we can answer

part of that question during our discussion of on board solutions. You are all very welcome to come on board.

Principally, on a ship level, it is safety by design, working up from the bottom to incorporate appropriate design features on the vessel. Very simply, that is gas detection and dual-wall piping or dual-wall approaches. Of course, we saw something catastrophic happen off the UK this week. Having worked extensively in Singapore identifying appropriate sites to conduct ammonia fuelling trials and so forth, I think it is important for there to be strong collaboration between the port authority, Governments and so on to identify appropriate areas to deploy this fuel.

Of course, in the UK and many ports around the world, sizable ammonia tanks have been in existence for many years. Ships have been carrying 50,000 cubics of ammonia for more than 50 years. It is nothing new, but that is not to be flippant. The most appropriate discussions to be had are to ensure that this is watched and monitored very carefully, with traffic control systems and so forth, so that you know the source of the vessels coming in and leaving, and setting up appropriate designated zones where you conduct those operations. In the UK, that will be in Teesside, Shoreham, Liverpool and elsewhere. Once you adopt those areas—call them "security zones" or "safety zones"—you can monitor very carefully what goes in and out. You have early warning systems for those vessels to take evasive action, such as if someone is steaming towards you at 16 knots for a certain period of time. There is nothing flippant there. It is a complex challenge to work on, but many more harmful fuels are carried around European and UK waters—Singapore and Australian waters, too—with no scrutiny whatever.

One benefit of bringing ammonia fuel to the table today is that we are being very honest and up front about the challenges. Our project has always been about striking off the challenges one by one rather than trying to hide them and then have them come up later. We have spent many hours in deliberation about how to create safety in conducting shore-to-ship and ship-to-ship transfers. It is important that the UK, perhaps through its institutes of higher learning, develops understanding around plume modelling so that we know how the ammonia molecule might behave in certain environments if there were a release. Those are all skills and capabilities that you should develop.

Lord Krebs: Thank you. Would James Kershaw like to add anything here? We have heard about measures to prevent a spill, but not what the impact would be if and when there were one, which there will be.

Dr James Kershaw: I echo what Andrew said. I have already touched on the public health impacts of a reactive nitrogen release. From an environmental perspective on some of the impacts of a potential spill, we have those direct and immediate toxic effects on marine life. There are also the effects of increased reactive nitrogen emissions going into the environment more generally. That could be longer term from a spill, the release of nitrous oxides from burned ammonia or N_2O emissions. These

effects include eutrophication—potentially, algal blooms and low-oxygen conditions. It has been shown to accelerate or cause ocean acidification, which is obviously extremely harmful for marine organisms. This also overlaps with efforts on climate mitigation, because certain habitats have been shown to be more sensitive to ammonia spills than others. For instance, estuaries, mangroves and wetlands are really important stores of marine and coastal carbon—blue carbon. Degradation of those habitats has the potential to impact on our efforts to mitigate climate change.

On measures to control some of these things, Andrew is exactly right that we need an open and honest conversation about this and it is great that we are having that. Also, controlling emissions of reactive nitrogen species from ship engines needs to be a holistic endeavour. We need to consider emissions of NOx, NH_3 and N_2O together, because in some cases measures to control one of those species from the ship engine might increase emissions of another. For example, use of selective catalytic reduction—SCR—can increase N_2O emissions. We pointed the committee to evidence for that in our written submission. We advocate that what is best for one reactive nitrogen species may not necessarily be best for another. We need an overarching, holistic approach that says, "These are all the emissions for reactive nitrogen. What is the optimum way to minimise these and their climate, safety, environment and public health impacts?"

Trevor Brown: For quantification of the environmental impacts from a catastrophic invent, I point the committee to the Environmental Defense Fund's report, *Ammonia at Sea*, which analyses the impact of a spill on multiple different ecosystems. That is probably the best source of literature on this topic and provides a good quantitative analysis.

The Chair: That is a suitable point for us to bring this session to an end. It has been very informative and I sincerely thank our panellists, not least Trevor Brown, who joined us all the way from the east coast of America at a very early hour. Please do not fail to send us the supplementary written evidence that you have kindly undertaken to supply. Many thanks. I call this session to an end.