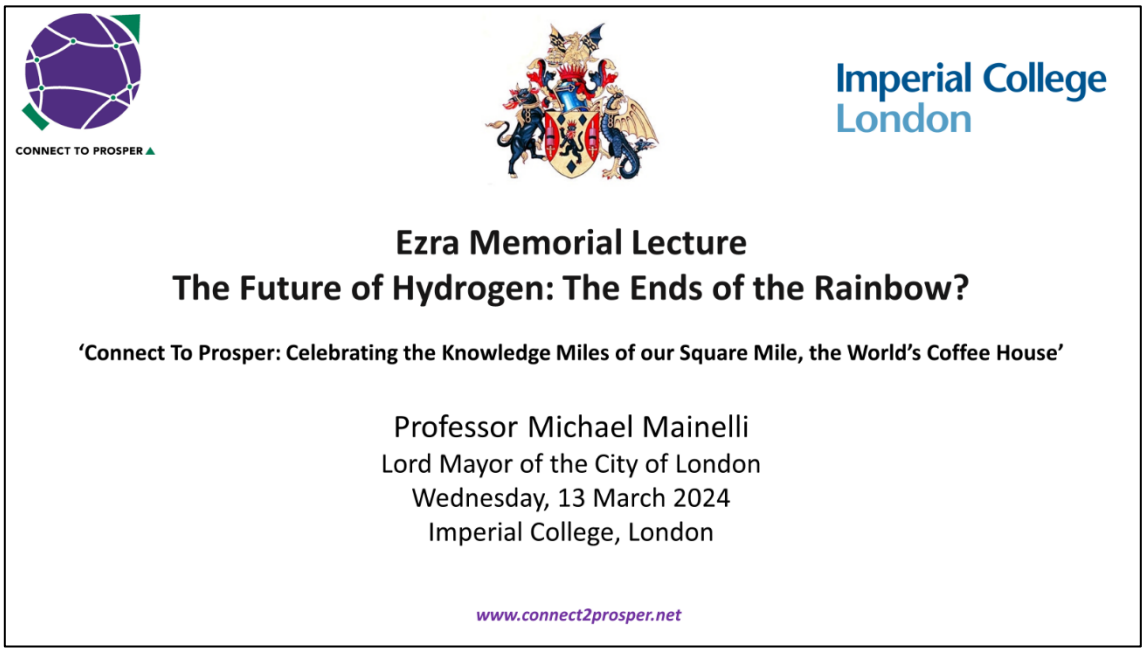
Ezra Memorial Lecture

The Future Of Hydrogen – The Ends Of The Rainbow

Alderman Professor Michael Mainelli
The Rt Hon The Lord Mayor Of London
Imperial College
13 March 2024



Good evening, It is my pleasure to open the 18th Ezra Memorial Lecture event honouring the life and work of Lord Ezra, former Chairman of the National Coal Board.

Agenda

- Atom
- Rainbow?
- Transport mechanism
- Industrial or domestic power system
- Energy trading mechanism
- 'Connect To Prosper'
- Discussion questions

"Get a detailed grip on the big picture."
Chao Kli Ning

Hydrogen presents a new economic opportunity for the UK, unlocking thousands of jobs and billions in investment, powering and decarbonising industry. The UK Government estimates that the hydrogen economy could create 100,000 jobs by 2050 and unlock £11 billion in private investment.

The government has set out plans to create a stable and secure hydrogen market. Industry and investors will be needed to make these ambitions a reality. Britain's longstanding energy-intensive sectors struggling to decarbonise believe hydrogen is their solution – tying the fate of many UK jobs and businesses to the growth of hydrogen in Britain.

Thinking internationally, gas is already exported to Europe and plays a vital role in keeping the lights on following Russia's invasion of Ukraine. Hydrogen could be the export of the future – replacing natural gas. Combined with Ireland, our islands' offshore production potential from wind and tide is enormous and hydrogen gas pipelines could be flowing west to east, including over England and Scotland, to northern Europe.

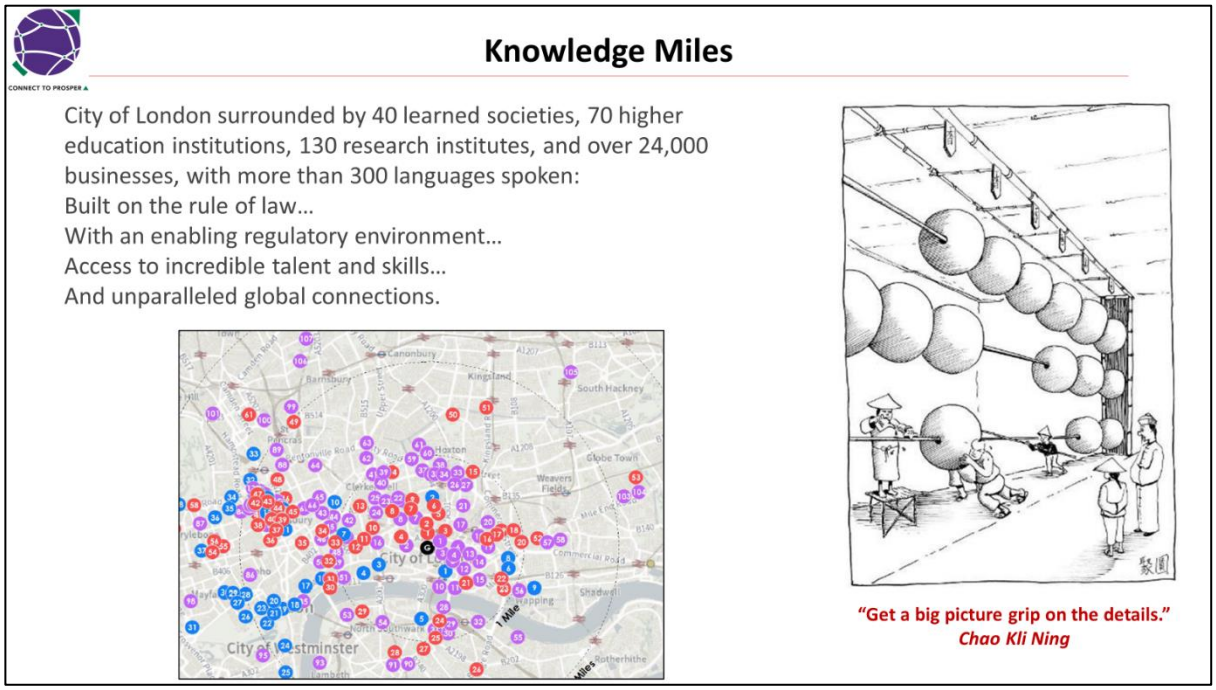
But if there's one thing you need to know about me, it's that I love a good dad joke, if there is such a thing:
Two hydrogen atoms walk into a bar. One says, "I think I've lost an electron." The other says, "Are you sure?" The first replies, "Yes, I'm positive."

If H2O is water and H2O2 is hydrogen peroxide, what is H2O4? Drinking, of course.

I intend to make four points about hydrogen:

- as a rainbow
- as a transport mechanism
- as an industrial or domestic power system
- as a global energy trading mechanism

To do so, I might point out that as the 695th Lord Mayor in an 835 year old post, I represent the Corporation of London, at just short of 14 centuries the world's oldest democratic workers' & residents' cooperative, the governing body of the Square Mile. We host some 615,000 workers, and 8,000 residents.



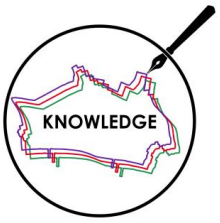
This year's theme is Connect To Prosper – celebrating the many knowledge miles of our Square Mile, the world's coffee house. Within two miles of Guildhall we have 40 learned societies, 70 higher education institutions, 130 research institutes; we also founded Imperial – sadly four miles away not two, City, City & Guilds, Guildhall School of Music and so on. With over 24,000 businesses, and more than 300 languages spoken, we have 200,000 engaged in finance and related services, and 200,000 scientists, engineers, and technicians. 8,000 of our 24,000 businesses are science, engineering, and technology businesses.

‘Connect To Prosper’

‘Celebrating the Knowledge Miles of our Square Mile, the World’s Coffee House’

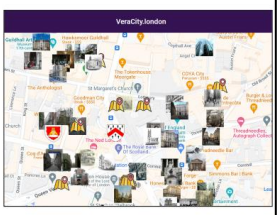
Five initiatives:

- The 695th Lord Mayor’s Ethical AI Initiative The 695th Lord Mayor's Space Protection Initiative a combined technology and financial services, initiative to use space debris performance bonds and other financial instruments to keep space 'clutter free' in aid of meeting 40% of the UN's Sustainable Development Goals;
- The 695th Lord Mayor’s Smart Economy Networks Initiative for smart economy networks, beginning with demonstrator projects in trade digitalisation, identity, pensions administration, cross-border credit referencing, and funds administration;
- “Constructing Science”, www.constructingscience.com, a standard for new build and retrofit lab conversions for those seeking to have biolabs in urban environments; hosting “The 695th Lord Mayor’s Constructing Science: Offices To Labs Initiative” events during ‘Connect To Prosper’ year;
- GALENOS - mental health ontology research project with MQ Mental Health to speed up research globally by two to three years.



Three programmes:

- Knowledge Miles – 100 online webinars and lectures on intellectual connections;
- Coffee Colloquies - 25 speed presentation events at Mansion House on the 17 UN Sustainable Development Goals and 8 other topics;
- VeraCity.London – the 695th Lord Mayor’s webapp of walks & wonders.

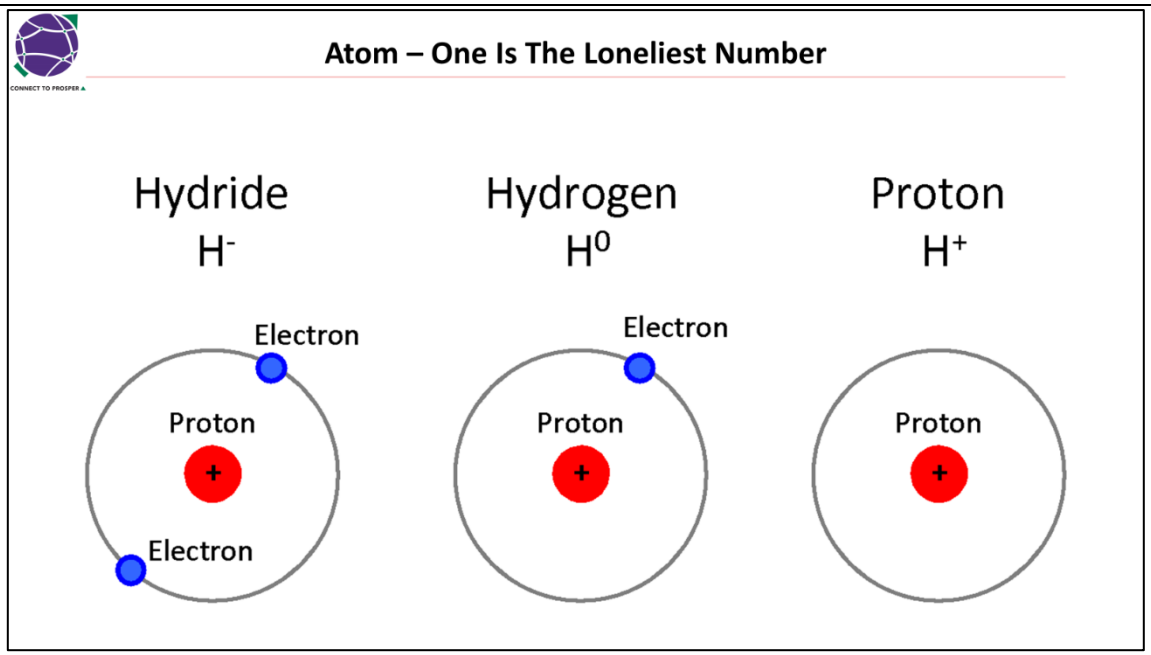


Fun: Lord Mayor’s Show, Paganini festival, Thames days, Bavarian Ball, Mansion House Badminton

…the City of London is the world’s ‘coffee house’ – a place where people come together, from across the globe, to find solutions to our planet’s biggest challenges. Coffee house culture spawned Jonathan’s Coffee House, opened in 1680, which grew into the London Stock Exchange, Lloyd’s Coffee House, 1686, Lloyd’s of London, and the Virginia & Baltick Coffee House, 1744, the Baltic Exchange. Great minds - Sir Isaac Newton, Sir Hans Sloane, Robert Hooke, and other members of the Royal Society – all frequent custodians of the Grecian Coffee House. The Guardian, Spectator, and Tatler all emerged from these ‘penny universities’. Mr Spock said, “Live Long & Prosper”; this year, “Connect Well & Prosper”.

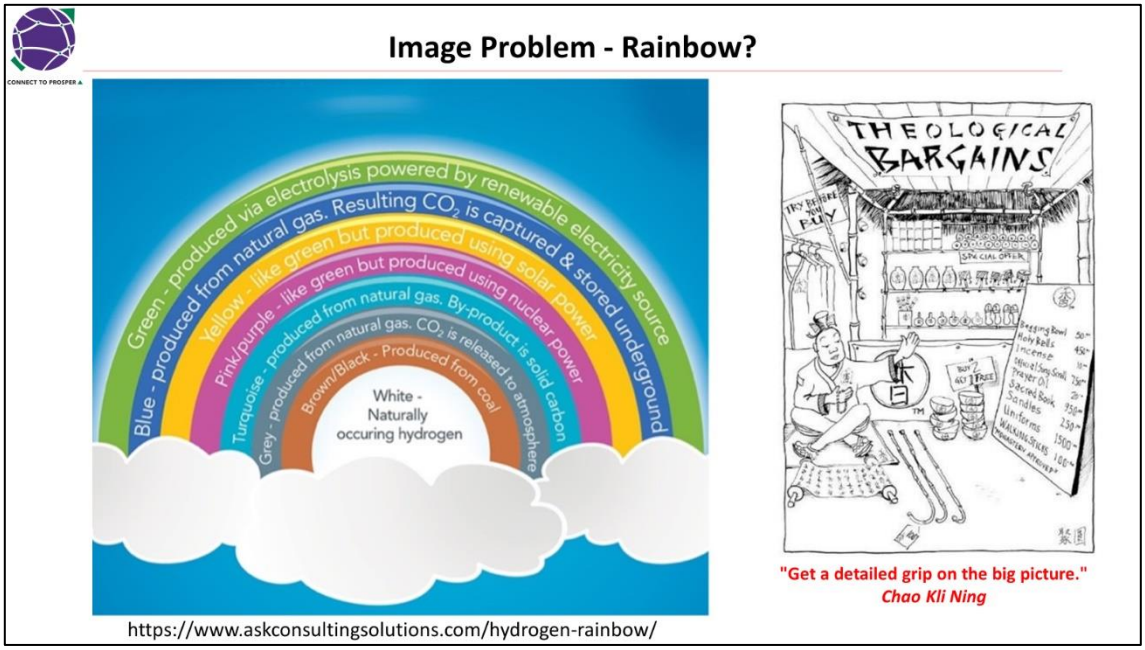
As A Rainbow

To start on hydrogen, I’ll just remind an Imperial audience of the characteristics - colourless, odourless, tasteless, non-toxic, and highly combustible. Hydro – “water” – and gen – “to produce”.



First discovered as an element in 1766 by Henry Cavendish, hydrogen is the most abundant chemical element: estimated to contribute *90%* of the mass of the universe. Hydrogen combustion produces no direct emissions of pollutants or greenhouse gases - qualities that give it *huge* potential as a clean replacement fuel in transportation, electricity generation, and industries cement and steel.

But while hydrogen is present in nearly all molecules in living things, it's very scarce as a gas – less than one part per million by volume. Leaving 'white', hydrogen we might 'mine' aside, we produce hydrogen from a variety of resources, such as natural gas, nuclear power, biogas, and renewable power like solar and wind.



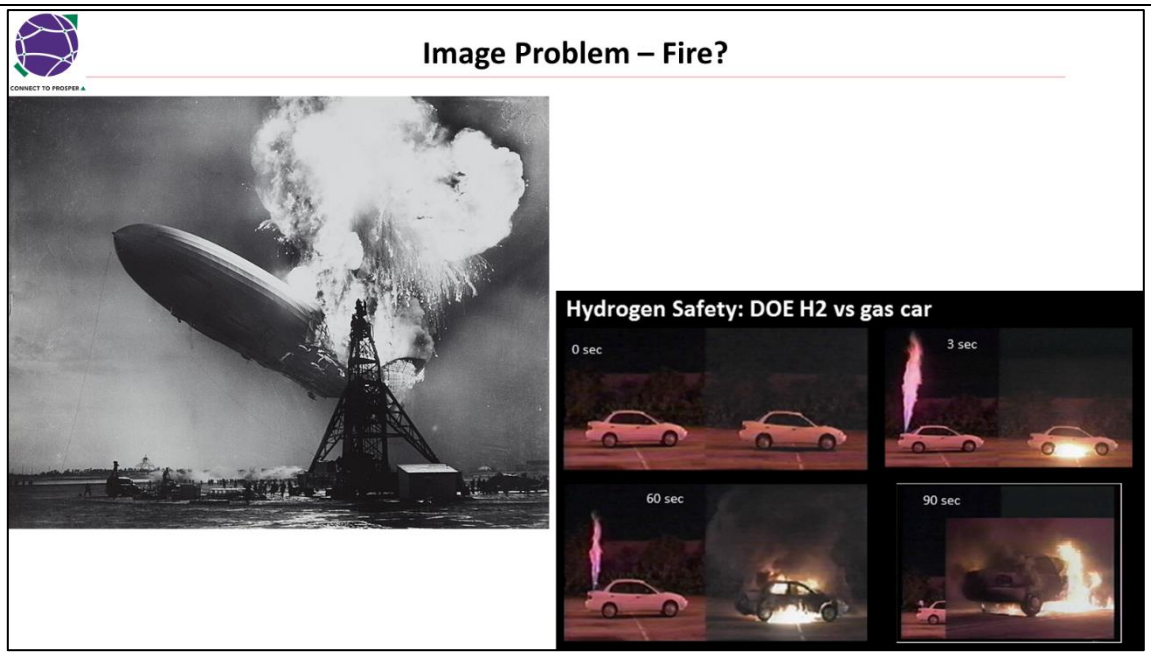
For a colourless gas, hydrogen sure generates a lot of colourful prose...from blue to grey, green, black, brown, yellow, turquoise, white, and pink (if not purple prose). When we split types of production into colours, I sometimes want to burst out into song à la Judy Garland, but my tune might be 'Waste of Time'.

The profusion of hydrogen colours is due more to the optics of economics than science and engineering. It boils down to whether you're going to produce it fully renewable (green)...or whether you have variants along the way.

I don't find the colours of hydrogen a useful concept at all, unless you apply the same thinking to electricity. In which case, you're just colouring energy projects with pretty pictures when charging for carbon emissions does the same job better.

At this point I wish to make a small leap over the issue of hydrogen electrolyzers. I look to learning curves for projections – the rate of cost reduction correlated to the production volume over time. The 2021 US Department of Energy's Hydrogen Earthshot anticipates an 80% cost reduction to $1/kg in 1 decade, i.e. 2031. In similar work for the London Accord with the Santa Fe Institute back in 2006 we successfully anticipated today's solar and wind power prices, 18 years later. Learning curves for alkaline, proton exchange membrane (PEM), and solid oxide electrolysers (SOE) are within a reasonable 5% to 15% per annum improvement zone. I'm also going to skip over storage issues as hydrogen seems compatible enough with current gas storage technologies before we touch on large-scale geological storage.

As A Transport Mechanism



While the vibrant terms we use to describe hydrogen are relatively new, hydrogen and transport have a long-shared history.

Hydrogen-fuelled dirigible and zeppelin travel was more common in the 1930s than some people realise. Indiana Jones' zeppelin flight was no fluke. But notoriously on 6 May 1937, having made ten successful trips to the US in the prior year, the gigantic LZ 129 *Hindenburg* - a German, commercial, passenger-carrying rigid airship – self-immolated during its attempt to dock in New Jersey. Of the 97 people on board of the 97 people aboard (36 passengers and 61 crew), only 35 were killed (13 passengers and 22 crew), plus one person on the ground: for a total of 36 fatalities out of a possible 97 people. The Hindenburg's sister ship, the Graf Zeppelin, had flown more than a *million miles* for *nearly a decade* on hydrogen before being grounded after the Hindenberg disaster. Fun fact, if there is such a thing from a tragedy - the *Hindenburg* actually had a smoking lounge!

While having access to detailed MoD archives in the 1990s I retrieved the Hindenberg papers. Studies from NASA and others conclude that the Hindenburg disaster was probably due to "incendiary paint", a mix of iron oxide and aluminium-impregnated cellulose, which are reactive together even after drying. Unlike gasoline or wood fires, hydrogen is far more buoyant as a gas which means that it is more survivable if you are below it, as seen in these comparisons of US Department of Energy tests on hydrogen versus petrol.

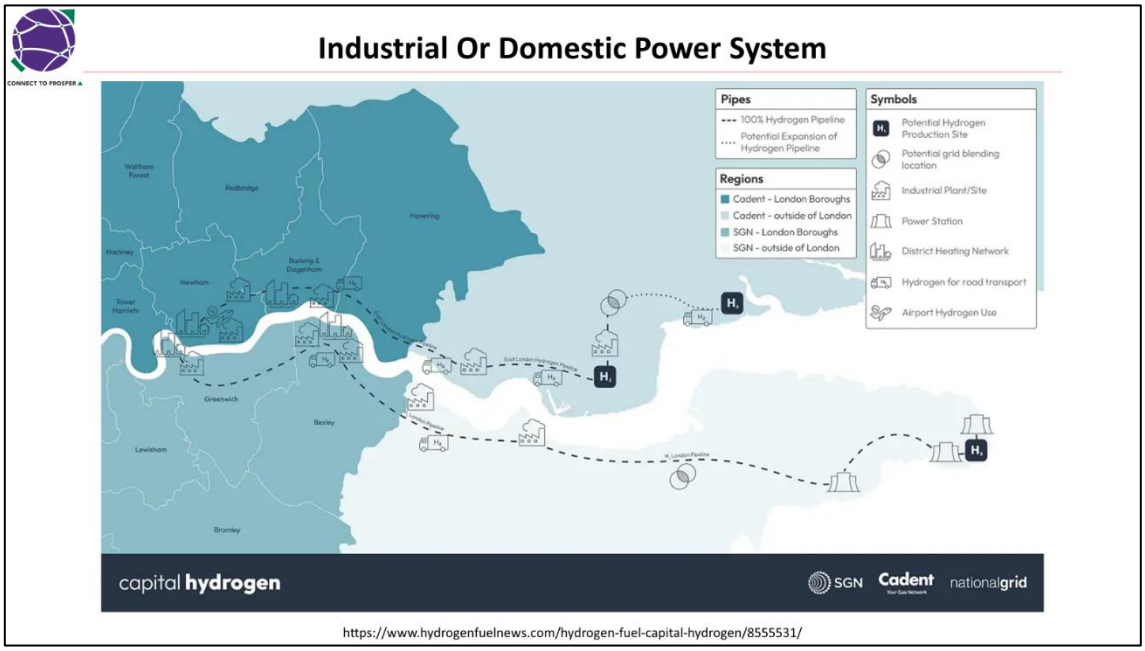
But hydrogen air travel is back. Last year, ZeroAvia announced that its 19-seater jet had completed a flight using nothing but green hydrogen, albeit a short flight.

The first internal combustion engine - developed in 1806 by Swiss inventor François Isaac de Rivaz - was powered not by gasoline but by a mix of hydrogen and oxygen. Today China has the highest number of hydrogen fuelling stations for road vehicles worldwide, where you can fill up just as you would with petrol or diesel. Late last year, Kawasaki unveiled the first hydrogen-powered motorcycle prototype. Indeed, there are currently over 25,000 hydrogen fuel cell powered forklifts operating in shipping fulfilment centres around the world. Your most recent online purchases may well have been moved by a hydrogen fuel cell vehicle.

Hydrogen does have an image problem, but is here to stay as a transport mechanism. The core dividing assumptions though are (a) whether there will be

enough fuelling infrastructure and (b) whether hydrogen makes economic sense for small vehicles.

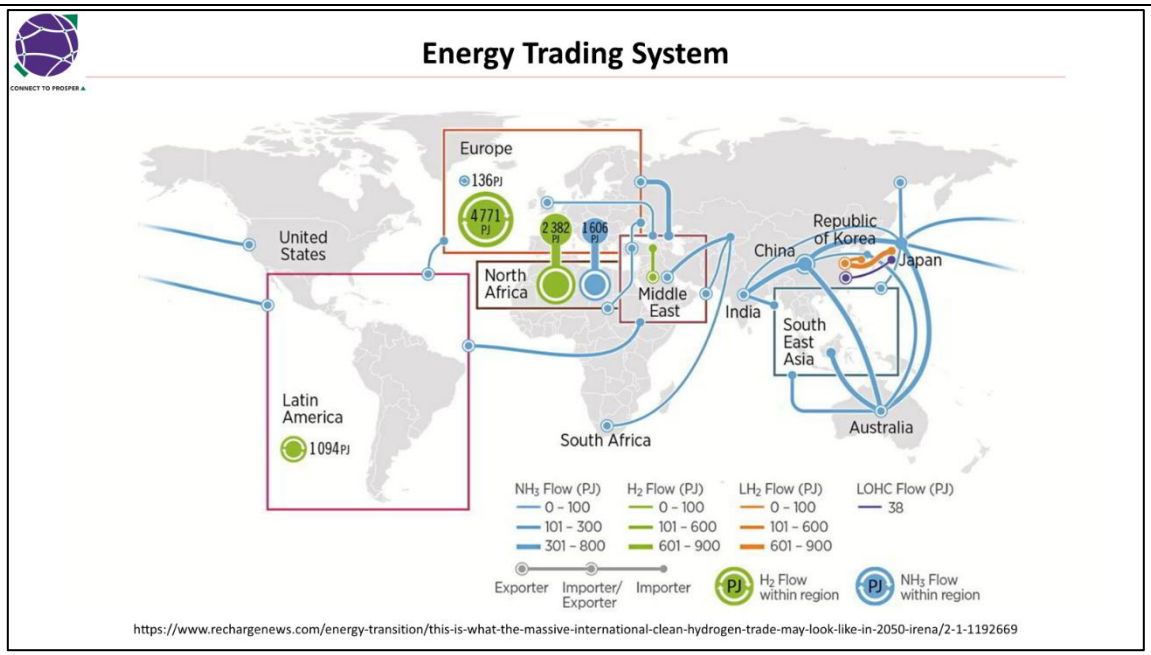
As An Industrial Or Domestic Power System



https://www.hydrogenfuelnews.com/hydrogen-fuel-capital-hydrogen/8555531/

We'll hear during discussion plans for hydrogen in the home or in the factory. We are divided by assumptions that we should go for electric energy transmission or gas energy transmission. I truly believe in options and thus support both camps. I believe that dual infrastructure is not inherently wasteful, think multi-modal transport, provides competition, and increases resilience. We can have both electricity and gas. Another example where pinning a rainbow on hydrogen but not electricity makes no sense.

As A Global Energy Trading Mechanism



Demand for hydrogen - which has grown more than threefold since 1975 - continues to rise. Globally, the past few years have seen the development of a number of National Hydrogen Strategies, new Net Zero targets, roadmaps for developing hydrogen infrastructure, transport and regulation, and billions worth of investments into the future hydrogen economy.

China is currently the world's largest consumer and producer of hydrogen. And while most of the hydrogen it makes is fossil-fuel-based, it has big plans to scale up its green hydrogen production and use the fuel to decarbonize sectors like steel and chemicals production.

Saudi Arabia is next on the list, thanks, in no small part, to the fact it's currently building the world's largest green hydrogen project - a joint venture between ACWA Power, Air Products, and Neom estimated to produce over 200 kilotonnes of green hydrogen per year: 156 more kilotonnes per annum than the largest existing green-hydrogen facility. And there are another 40-odd substantial hydrogen projects in the KSA in the pipeline; with another 25 in the UAE.

Sweden, the US, and the UK round out the top five countries with the most ambitious green hydrogen plans. The UK launched its Hydrogen Strategy, with a 'twin track' approach supporting both 'green' and 'blue' hydrogen and an ambition for 10GW of production capacity in 2030. In Utah, developers are using water to dissolve geological salt domes to create two huge caverns - each as deep as the Empire State Building is tall - to store green hydrogen underground. Meanwhile, Namibia's government has formally signed an

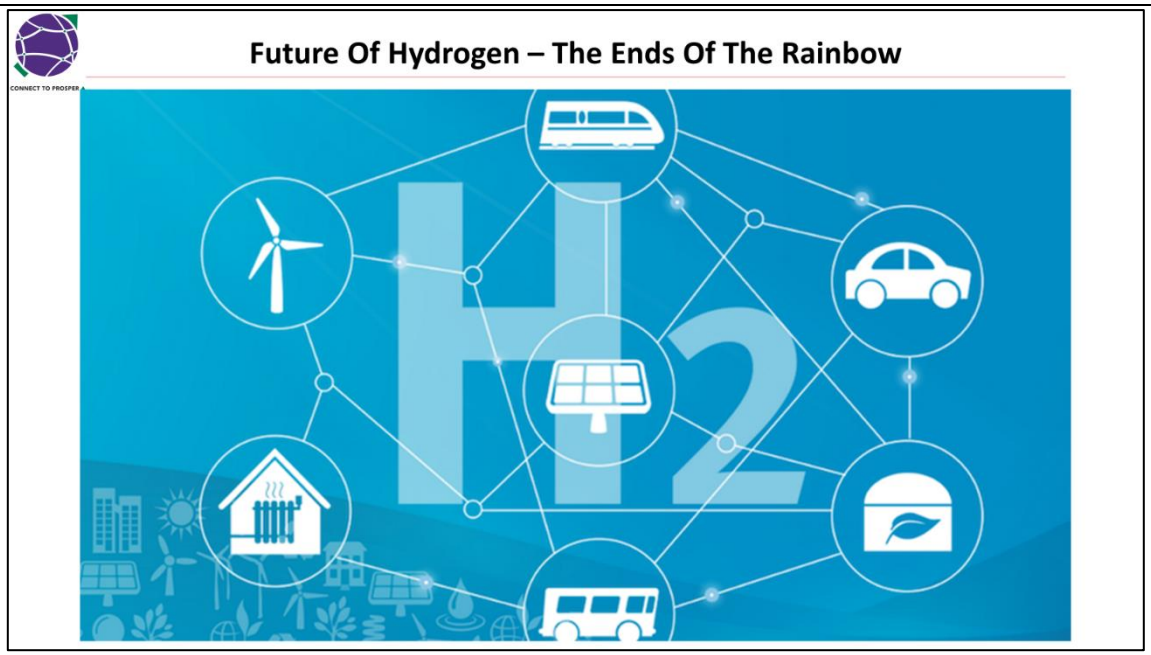
agreement with independent producer Hyphen Hydrogen Energy to develop a $10bn green hydrogen and ammonia complex in the country.

One initiative focused on pump-priming hydrogen onto the world is the H2Global Foundation. Launched in 2021 with support from the EU Commission, H2Global is funding €7.5bn of off-take agreements such as Namibia's, underpinned by the notion of a "double-auctions model". This means hydrogen is purchased through a first auction on global markets, with suppliers offering the lowest price entering long-term contracts.

The trading question for all of us is how much large-scale energy transfer will be required via pipelines or shipping. Energy products transported by ship were approximately 36% of global seaborne trade in 2021, with around 15% of coal, 17% of natural gas, and 64% of oil produced globally moved by ship. Note too that Kawasaki's Suiso Frontier experimental ship in 2022 demonstrated liquified hydrogen delivery of 75 metric tons (1,250 cubic meters). In 2023 they laid the keel for a 10,000 metric tons (160,000 cubic meters) vessel and anticipate a commercial fleet in 2030.

As the world heads for net zero by 2050, or 2060, what happens to large-scale energy trading? Assume that coal, gas, and oil trade becomes negligible, but that traded hydrogen (as methane or ammonia or liquid hydrogen) trades at 50% of today's level. It's still a huge traded market.

As for pipelines, renewable wind capacity alone in Scotland is over 11GW. Wind potential in the North Atlantic around Ireland is such that generating between 30GW and 70GW is achievable. We need some huge pipelines from Ireland across Scotland and England to northern Europe. Time to get cracking, or that being an oil refinery term, should I say electrolyzing? Our only difficult assumption is the scale of locally-generated energy using new renewable technologies.



Conclusion

To conclude, we've established that there *is* somewhere over the rainbow. No matter what colour hydrogen is, it's here to stay. Not as a rainbow but:

- as a transport mechanism – core assumptions on future vehicle sizes and infrastructure – my take is dual electric and hydrogen;
- as an industrial or domestic power system – core assumptions on future of domestic piping and heating – my core assumption is dual electric and hydrogen;
- as an energy trading mechanism – core assumptions on the need to continue to trade large energy quantities globally – my take is yes, we'll trade at least at 50% of today's capacity.

To finish, may I share one last dad joke. A hydrogen molecule gets arrested. His mother comes down to the police station to bail him out. She is met by the detective working the case. "I don't understand it", says the mother. "Hydrogen was always a good kid. I never had any problems until he met oxygen." "Don't worry", says the detective. "The situation is fluid but he won't be charged."

I'd like to thank the Worshipful Company of Fuellers for organising tonight's event...Imperial College London's Energy Future Lab for hosting...and Cadent Gas for supporting the reception. Thank you, in advance, to our brilliant panellists:

- Jon Clark, EY, Chair of the Fuellers' Industry Group;

- Professor Stephen Skinner, Professor of Materials Chemistry at Imperial College London;
- Dr Angela Needle, Strategy Director at Cadent.

So, the closing question: "optimistic or pessimistic?":

The scientist says "pessimistic: the task is too complex."
The economist says "pessimistic: nature doesn't pay."
The politician says "pessimistic: there's no global consensus."
But this Lord Mayor says "optimistic: pessimism is for better times".

Our hope is that tonight's discussion provides you with ways to see the future of hydrogen through an economic prism, less darkly. Thank you.