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Negative Emission Networks

Phone Calls That Clear the Air

Much research and standards work has been invested in making telecommunication networks greener, more energy efficient and more environmentally efficient.

There are various techniques that can be used to reduce the amount of energy consumed by a telecommunications network. Network sharing is one of the most important. Telecommunications networks can also help save the planet by reducing the need to travel. The productivity and environmental gain from 'the zoom boom' is one of the few saving graces of the Covid pandemic. It is however impossible to ignore the fact that moving and storing bits consumes profligate amounts of power. Home cinemas and giant TV screens exacerbate the problem.

This does not matter if the power is generated from renewable sources, wind, waves, solar, hydrothermal and geothermal but wind, waves and solar are intermittent and energy storage to date has been expensive and inefficient.

A chance encounter with a neighbour, a strategist for one of the largest petro producers on the planet, introduced me to the concept of using ammonia to navigate from a carbon economy to a negative emission hydrogen economy, a story in which the oil, gas, energy and chemical industries, the heavy lifters of the carbon age, could turn out to be the saviours of the planet.

Coincidentally the man credited with bringing liquefied natural gas on shore from the North Sea in the early 1960's, Sir Kenneth Hutchison, lived in our house from the 1930's through to the late 1980's, writing a book about the experience titled perhaps a little unimaginatively, High Speed Gas. The transition from coal as a source of gas, the town gas to natural gas transition, had environmental benefits but also generated hundreds of billions of dollars for the UK economy. We are still not sure where most of that went.

My neighbour explained how sixty years later the oil and gas industry plan to use oil field infrastructure in reverse starting with the North Sea to prove the economics and environmental model. The reverse infrastructure plan is partly based on using existing pipelines to ship industrial carbon captured from carbon intensive processes, old power stations and steel and cement plants to exhausted oil and gas fields for a decent burial. But also every oil rig will become a hub for a local wind farm with the electricity used to produce ammonia which can be shipped as a liquid at ambient temperature via existing pipelines back to shore based terminals. Ammonia is already shipped in bulk through continental pipelines.

Ammonia has an energy density of 15.3 MJ/ litre compared to the 4.0 MJ/litre of hydrogen at the awkward atmospheric pressure of 500 atmospheres though by mass the relationship is inverted. On balance, ammonia is an efficient way to move hydrogen around. By contrast, getting electricity back from deep water wind farms where the wind blows hardest is hazardously expensive. A broken or faulty undersea power cable can cost tens of millions of dollars to repair.

Ammonia in highly concentrated solution is fatally toxic but we use it every day in small amounts to clean windows, drains and toilets. Like many gases it needs to be treated carefully but can be managed.

The standard way of producing ammonia (NH_3) is by steam reforming though this requires significant heat and produces coke as a by-product. The Haber process, for which Fritz Haber won the 1918 Nobel Prize, is also used to combine nitrogen from the air and hydrogen from natural gas by increasing pressure to 200 atmospheres, heating the gases to 450 degrees C and passing them through a tank containing an iron catalyst.

The Haber process can be deployed to provide an end of life revenue opportunity for nearly exhausted gas fields. Methane from sewage works, land fill or warming permafrost is another source. An alternative is to pump nitrogen gas from the air across a copper coated catalytic screen to interact with water, of which there is a plentiful supply in the North Sea. The economic and environmental credentials of ammonia depend on making these processes less energy intensive and ensuring the energy used is renewable.

With this in mind, the oil and gas majors are also investing in ammonia production from solar power and we talked about a new 4 gigawatt solar farm in Saudi which will be bulk shipping ammonia within 3 to 5 years. The annual output of ammonia is around 100 million metric tons, mainly used as nitrogen based fertiliser. It is already a scale economic easily shippable bulk commodity.

Combining hydrogen from hydrocarbons with nitrogen from the air is an energy intensive process with a large carbon footprint. Combining nitrogen from the air with hydrogen from water is also energy intensive involving cooling the air to the point at which nitrogen becomes liquid and extractable, a process known as fractional distillation or by compression absorption and then compression. The process is environmentally benign provided renewable energy is used and is part of the longer term plan in Saudi to switch from hydrocarbons as a feed stock to water and air with solar providing the power for production. Wave power, hydroelectric power and geo-thermal power can also be used.

At the shore terminal, care has to be taken to ensure the ammonia is oxygen free. If oxygen is present the hydrogen yield will be produced and oxides of nitrogen will be produced which are both directly and indirectly detrimental to the troposphere. Care also needs to be taken that oxygen is not introduced during onward transportation to garage forecourts where it is stored in existing underground tanks previously used to store petrol.

The ammonia therefore has to be pure when it is poured into a car. Ammonia is non-flammable. The hydrogen that is separable from the ammonia is highly flammable though with a relatively low CO_2 footprint when burnt. One of Mr Musk's hydrogen and liquid oxygen rockets has a lower CO_2 footprint than a 747 flying from Heathrow to New York.

Ammonia can be burnt as a fuel in modified car engines. It was used to fuel buses in Belgium in the Second World War and occasionally since on a demonstration basis. An octane rating of 120 and a low flame temperature means that high compression ratios can be used without high NOx emissions. As ammonia does not contain carbon there is no carbon dioxide, carbon monoxide, hydrocarbon or soot. This is sometimes described as Blue Ammonia, a fuel that when burnt produces no greenhouse gases. If produced with renewable energy it is called Green Ammonia. The ACWA Power Company has a small scale production plant for green ammonia (and green hydrogen) in the new Saudi city state of Neom. It can also be burnt in truck and train engines and ships and aeroplanes and even in air ships where it could also be used as a lifting gas.

However we do not need to burn ammonia or the hydrogen extracted from ammonia but can use it in a fuel cell which is a zero carbon rather than low carbon electro chemical process with the potential to be negative carbon.

First the hydrogen needs to be extracted from the ammonia. As highlighted above, traditional processes require a temperature of 400^o C degrees but alternatives are now available that work at lower temperatures, typically around 60^o degrees.

The process is explained courtesy of the Chemical Engineering Journal (The Chemical Engineer).

The N-H bond within ammonia is extremely strong. A terpyridine bis (phosphine) molybdenum (I) cation is used to bind to the ammonia. This weakens the N-H bond to the extent that it becomes thermodynamically favourable for one of the H atoms to break away and bind to another H atom, forming H_2 gas. The reaction leaves behind a molybdenum-amido complex – [Mo]-NH_2. This can be converted back into the original molybdenum-amido complex – [Mo]-NH_3 – using acids and reductants, for reuse.

The hydrogen is then fed to the fuel cell.

The fuel cell consists of two electrodes—a negative electrode or anode and a positive electrode (or cathode) with an electrolyte in between. Hydrogen is fed to the anode, and air (oxygen) is fed to the cathode. The catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with the oxygen from the air and the electrons to produce water and heat which can be redirected back to the ammonia hydrogen separator. The water is clean enough to drink or pour on your plants or on trees and fruit and veg and the odd Palm Tree or three.

The process typically has an efficiency of 60%. By comparison a petrol engine has an efficiency of 20% to 30% and a diesel engine has an efficiency of 40%.This efficiency gain off sets the lower energy density of ammonia relative to petrol and diesel.

You can buy a hydrogen powered car today or a bus and a truck or in the future a train, and hydrogen powered aircraft are promoted as an alternative for the aviation industry. There is however a weight problem. Hydrogen cars are available from Toyota and other manufacturers including Hyundai. The second generation Toyota Mirai introduced in late 2020 is an improvement on the first generation car introduced in 2017 but the 5.6 kg of hydrogen is housed in a tank that weighs 93 kg. A lithium ion battery weighing 44 kg is also needed to recover energy from the braking system and provide extra power when needed to the electric motors. A lithium battery will also be needed in an ammonia powered car and both power trains will need a DC to DC converter which in the Mirai weighs 25.5 kg.

The ammonia car however does not have the weight overhead of a 500 atmosphere fuel tank. It also shares the advantage of a petrol engine that fuel weight reduces with distance. The battery in your Tesla will still weigh 500 kilogrammes whether it is full or empty. This is also the reason why battery powered aeroplanes are less weight efficient than ammonia powered hydrogen powered aeroplanes.

The battery brigade does of course have the ability to bite back. Israeli company StoreDot, backed by Eve Energy in China and Daimler, BP, Samsung and TDK, has recently announced an 'extreme fast charging battery' that can be fully charged in five minutes. This means that batteries can be downsized reducing cost, weight and releasing space. The problem with existing lithium ion batteries is that graphite is used as one electrode through which electrons are forced to store charge. Rapid charging can result in the ions clumping together, short circuiting the battery. The StoreDot battery uses semiconductor particles which absorb the ions more easily, initially Germanium but soon to be replaced with silicon.

Mr Musk approaches the problem differently, using software to sequentially charge cells which are not much larger than an AA battery. He and fellow travellers Enevate and Sina Technologies are also looking at solid state batteries as well, including super capacitor technology. Companies such as Echion are researching compounds such as niobium nanoparticles. Nano materials using nano particles (sub-micron particulate particles) are deposited on a substrate in a mono layer. This gives them distinct properties that are different from the compound when used use in deeper depositions. Keeping battery packs at an optimum temperature for charging is also widely used. This uses energy but is essential for longevity.

The bigger issue is how to get enough electricity to 8000 petrol forecourts in the UK. On a warm day with the wind behind you, a Tesla will go about 4 miles on a kilowatt hour of electricity. So a ‘full tank’ (say 400 mile range) is 100 kilowatt hours of battery capacity which takes half an hour of fill time using one of Tesla’s 200 kilowatt fast chargers.

To increase this to a petrol equivalent fill rate of three minutes equates to 1000 Kilowatt hours per pump which is one Megawatt multiplied by 18 pumps per forecourt which is 18 Megawatts multiplied by 8000 forecourts which equates to 144,000 Megawatts which is 144 Gigawatts. Sizewell C will have an output of 3.2 Gigawatts. It is relatively easy to build more Sizewell C’-s but it will take 30 years and there is a risk of them melting into the Suffolk sand.

Or we could increase forecourt capacity by a factor of ten and drink a lot of coffee. Charging at home distributes the load over a 24 hour time period. Homes are limited to a 60 amp power main which sets the maximum charge rate at 7.5 kilowatts but there will still be a risk of brown outs and the occasional black outs including digital blackouts when networks go beyond their back up energy limits. And not all of us are able to have a home charger.

Additionally there is the need to upgrade the transmission and distribution network. Improving the long distance and local electricity supply network is good news for high voltage engineers but not so good for electricity grid owners. The breakup of the Central Electricity Grid in 1990 and deregulation of the sector has resulted in power networks in the UK being owned by multiple entities of which less than 10% are based in the UK. This is called TAKING BACK CONTROL. Upgrading lamp posts as Megawatt charge points comes with similar technical and commercial challenges.

So if BP and their fellow travellers put fast charge electric pumps on to every one of their UK forecourts and councils roll out megawatt lamp posts there will be a risk of supply issues particularly when everyone puts the kettle on at once. For comparison, a sodium street lamp is typically rated at 70 watts. Even 7.5 kWh charging when scaled across all lamp posts in a city represents significant additional load.

News that Shell is buying one of Europe’s largest on street charging companies, the German company Ubitricity following on from the acquisition by BP of Chargemaster and its network of 7000 UK charge points, some of them broken, indicates that the oil majors are hedging their bets but how the cost of maintaining these multiple charge points will be recovered is a future unknown. At least garage forecourts have sandwiches and firewood as an income stream.

According to the European Alternative Fuels Observatory there are 570 EV charge points for every 100 km of road in the UK. Zap Map estimate that by the end of 2020 there were 11,293 public charging points with 18000 devices providing 31,500 connections, 7,600 of them ‘rapid’ (20 kWh and definitely not 200 kWh). The charge points are a bizarre mix of AC and DC units with a bewildering array of membership schemes and payment options. This is just about tolerable at present levels of EV ownership but sales increased by 184% last year. In Norway, 54% of all cars sold last year were electric with 98% of the power supplied from geo thermal and renewables. This is not easy to replicate in other countries, for instance not many countries have geothermal as an option. Ammonia as an alternative or at least supplemental energy carrier therefore makes sense. It may also be the answer for domestic and industrial and commercial heating where gas is destined for replacement. Heat pumps in every house would represent another massive hit on the grid. It may be better to deliver ammonia down the gas pipes.

The most persuasive argument for ammonia is however its ability to produce clean air as a by-product of the nitrogen and hydrogen and oxygen cycle.

On a small scale in a car, oxygen is sourced from air drawn in through the front of the car through a catalyser that takes out sulphur dioxide and nitrous oxide from the atmosphere. A filter takes out particulates down to 2.5pm. The output from the exhaust pipe is drinkable water.

On a large scale, a fuel cell power station draws air in which is then cleansed of sulphur and nitrous oxide and filtered for particulates then used in the fuel cell with the same by product as the small scale process, drinkable water. It is cheaper and safer than nuclear power. We could call it Sizewell D with the D standing for Decarbonation. Oxygenation of the air becomes integrated with the clean water treatment downstream of the fuel cell. It is hard to beat bubbles as an oxygenation process.

Active systems for cleaning air have been around for decades. Amine solvents, organic compounds *derived from ammonia by replacement of one or more hydrogen atoms by organic groups* have been used to clean hydrogen sulphide, acid gas, from power station flues since the early 1950's, producing a residue of soluble carbonate salt.

Ambient air can be cleansed by passing air through activated carbon, otherwise known as charcoal also known as a sorbent or with zeolites or as they are more correctly described *hydrated aluminosilicate minerals made from interlinked tetrahedral of alumina (AlO_4).* The term means 'boiling stone' in Greek and was coined by the Swedish geologist Axel Frederick Cronstedt in 1756 *to* describe what happens when you heat rocks that are able to trap water. Zeolites are used in cat litter and water softeners. The efficiency of these cleaning systems can be increased when combined into membranes with single atomic layer deposition also known as nanoparticles and nanomaterials, collectively described as Metamaterials.

Any renewable energy source, deep water wind farms, in shore wind farms, land based wind farms, solar, waves and hydro thermal can store excess energy by producing ammonia which can be reused locally or shipped elsewhere. An off grid solar powered base station with integrated fuel cell becomes self-sustaining, as do those gigantic server farms sitting somewhere on the edge of your network. A solar powered ammonia production plant in the middle of a desert can support a fuel cell that generates energy and water for local irrigation and support a local communication network.

But also there is no longer a carbon cost associated with drawing power from an electricity grid supplied from power stations which are scaled up fuel cells which draw air from the atmosphere. It could be argued that taking this much oxygen from the air would cause its own set of environmental issues but the extraction of hydrogen from water by electrolysis produces oxygen. The recombination of the electrolysis products produces energy.

Oil majors can of course be accused of green washing. On every metric, a gallon of black gold gushing out of the ground costs less than a gallon of ammonia both in terms of (literally) sunk cost, energy cost and even it could be argued environmental cost when compared to ammonia and/or hydrogen extracted from hydrocarbons using non-renewable energy so there are reasons for the oil majors to maintain the status quo.

On the other hand, a negative emission economic model combining upstream carbon capture and downstream ammonia is compelling and suggests that there will be a point where a gallon of ammonia realises more added value than a gallon of oil.

That tipping point may be sooner than expected. Mr Musk has proved you do not have to make a profit to make a profit. A fraction of Tesla's stock appreciation would put a smile on an oil financier's face and if the rate of transition from a petro to ammonia economy drives oil stocks upwards, the transition will happen quickly.

Rapid decreases in battery cost and improved battery performance will hasten the oil major's move into the broader power generation market. And Mr Musk is not yet in charge of the electricity grid so that problem still needs to be solved. There will be resistance points including the dependence of governments on petrol tax but if going green via ammonia produces green backs than the ammonia green rush will be under way and if petrol tax is replaced with ammonia tax our state pensions will be safe as well.

So sit back and relax; the planet is saved courtesy of the Negative Emission Negative Carbon Network. Those nice chaps at BP and Shell and British Gas will help us towards the sun lit uplands of a sub-zero carbon economy world. When ethics, energy, the environment and economics align everybody wins. Sir Ken would be proud of us all.

Thanks to Stirling Essex for proof reading and to Rob Jacobs for correcting the school boy chemistry errors.

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