Electrons and Molecules
Fenex CRC Annual Conference

Alan Finkel
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Final

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On first hearing the conference theme “develop, de-risk and decarbonise”, if I were an economist, my mind might have jumped to important issues of international financing. If I were a digital-tech engineer, my mind might have jumped to the software for constantly matching supply and demand in the electricity grid.

Instead, because of the feet-on-the-ground challenges to keep our global economy humming and growing while we decarbonise, my mind immediately jumped to the electrons and molecules that provide the energy we use on a daily basis.

The reality is that our energy supply enables our modern civilisation. There are no alternatives to maintaining and expanding the global energy system.

For example, putting limits on global population growth has often been proposed by theorists but never put on the agenda for international climate change negotiations.

The probability of the majority of Australians and citizens of other economically developed countries giving up international travel is zero.

And the likelihood that the majority of the word’s population will become vegan is rather small.

We have to maintain our energy supply, but the associated emissions are a huge problem. Despite the aspirations of the Kyoto meeting in 1997 and the Paris Accord in 2015, global emissions continue to rise.

Nearly three quarters of those global emissions come from using coal, oil and gas.

Ultimately, these fossil fuels will be replaced by electricity, and where electricity is inadequate, we will use hydrogen and its derivatives.

In Australia, the electricity will be solar and wind. In other countries, hydroelectric power and nuclear power will play a role, too.

Coal will go early, but oil and gas will be with us for many decades.

That’s why my mind turned to electrons and molecules. Not just any electrons and molecules. No, I started thinking about the type you would want as a friend, the type you would invite for dinner to introduce to your parents.

At my dinner table, I want *clean* electrons and *clean* molecules, reliably supplied and not too expensive.

Electrons have always been on the menu for me because I was trained as an electrical engineer. Then, seven years ago, electrons were elevated to three-hat Michelin status when I was asked to review the National Electricity System. And molecules became my favourite desert when I was asked to chair the development of the national hydrogen strategy.

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Some might ask, “electrons *or* molecules?” but answering that question would be impossible because the clean energy future needs the magic of electrons *and* the flexibility of molecules.

Nevertheless, the balance between them is shifting.

Today, most household heating energy comes from combustion of methane molecules, but the shift to electrons driving heat pumps – also known as reverse cycle air conditioning – is underway. The prospect of hydrogen filling a role in domestic heating is diminishing every year partly because of the energy efficiency advantage of heat pumps and partly because the electric heat pump industry is moving much faster than the hydrogen heating industry.

Today, most transport is powered by hydrocarbon molecules in the form of petrol, diesel, bunker fuel and jet fuel. The shift to electrons for cars and commercial vehicles is well underway. The shift to hydrogen-treated modern biofuels, hydrogen itself, ammonia or synthesised hydrocarbons for heavy duty road transport, shipping and aviation is just beginning.

Completing these shifts will take decades, not just in Australia, but globally.

In the meantime, we must make sure that the fossil fuels we use today are extracted and processed without fugitive and process emissions.

Equally, we must make sure that hydrogen-based fuels can be produced with minimal lifecycle emissions, at reasonable cost and in great abundance.

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There is a lot to be done. The Fenex CRC is working on the decarbonisation of LNG production. For the LNG industry to achieve this goal, fugitive emissions must be substantially eliminated, and production processes, such as liquefaction, must use zero-emissions electricity.

For a long time, the problem with using solar and wind electricity for those production processes has been the need for a 24/7 supply.

Up until recently I was unsure how that could be achieved, but from site visits, discussions and new reports, I am now convinced that by the end of this decade, batteries to support solar and wind generation at an isolated site will take us nearly all the way there.

Battery availability and performance are exceeding all expectations. That's been obvious for a while. What has been less obvious is that despite the recent upturn in pricing because of Covid and Ukraine war-related supply-chain bottlenecks, the price of batteries will plummet.

One reason is that lithium ferrous phosphate battery chemistries will become common for utility-scale, stationary batteries. In these, cheap iron and phosphate replace expensive nickel and cobalt. True, expensive lithium is still needed but the global lithium supply is likely to increase, and the elimination of the nickel and cobalt will significantly reduce costs.

Another reason is the expected boom in sodium-ion batteries. These do not use any rare or expensive chemicals at all. They contain sodium, carbon and various combinations of small amounts of tin, phosphorus, iron and manganese oxides.

Just two years ago, sodium ion batteries were not taken seriously, but then the Chinese battery manufacturer CATL – the largest battery manufacturer in the world – announced that it was planning mass production of sodium ion batteries.[i]

In February this year, a little-known Chinese brand called JAC, in partnership with Volkswagen, to my great surprise, released the world's first car to be powered by a sodium-ion battery. It can drive 250 km, be recharged to 80% in 15 minutes, and is rated for 4,500 charge and discharge cycles.[ii]

The world's two biggest battery manufacturers, CATL and BYD have announced that mass production of cheap sodium-ion batteries will start this year.

Just a year ago, I thought that to achieve 24/7 renewable electricity, a site would need batteries for four-hour storage, shifting to a mix of pumped hydro and hydrogen storage for longer durations.

Now I can see a near-term future where batteries such as lithium ferrous phosphate and sodium-ion will provide grid-scale storage needs all the way out to 12 hours, and longer if needed.

They will probably outcompete future pumped hydro on all-up capital costs, and because of their high round-trip efficiency will outcompete hydrogen energy storage and compressed-air energy storage on operating costs.

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Now to hydrogen.

On this, the Fenex CRC website says, “with the growing global need for cleaner energy Australia needs to seize the opportunity to help grow a Hydrogen export industry.”

The government has heard the message! As you will be well aware, on Tuesday night, Treasurer Jim Chalmers announced a two-billion-dollar *Hydrogen Headstart* program to help scale up Australia’s hydrogen industry. The program will provide revenue support for large-scale projects through competitive production contracts.

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In anticipation of the growth in our hydrogen industries, there are two things I would like to discuss. First, how hydrogen should be exported, and second, the standards to which blue hydrogen should aspire.

Let’s start with blue hydrogen. Contrary to what many have publicly proclaimed, blue hydrogen has every right to sit alongside green hydrogen. The end product is identical. What counts is that the production emissions of carbon dioxide must be very low.

For blue hydrogen to be successful in a decarbonising world it must be subject to a certification scheme, such as the Australian government’s Guarantee of Origin scheme, which measures the emissions of carbon dioxide during production.

To achieve a low emissions-intensity score, the upstream emissions must be negligible, and the emissions from all aspects of the production process must be captured and sequestered.

Achieving a high percentage capture rate will likely require brand new processing equipment designed to use renewable electricity for its process heat and process pressure.

What, then, is a reasonable target for the emissions intensity in blue hydrogen production?

As a baseline, let’s compare the production emissions intensity to the direct use of methane. The comparison is application dependent, so let’s go for the simplest use case, which is direct combustion.

In direct combustion of methane, the CO2 emissions are 50 kg per GJ.[iii] This is what you would get from burning hydrogen if the production emissions intensity were 6 kg of carbon dioxide per kg of hydrogen produced.[iv] Thus, at a production emissions intensity of 6 kg per kg of hydrogen, there is no advantage from using hydrogen and it would not be worth the incredible effort compared with using the natural gas directly.

The US climate legislation known as the Inflation Reduction Act, or IRA, explicitly recognises this. The tax credit depends on the production emissions intensity based on a lifecycle analysis.

The tax credit is zero if the production emissions intensity is above 4 kg of carbon dioxide per kg of hydrogen.

The tax credit is a tiny 6 cents per kg of hydrogen if the production emissions intensity is between 2.5 and 4 kg of carbon dioxide per kg of hydrogen. It is arguably an insult, not a reward.

The tax credit rises to a mere 7.5 cents per kg of hydrogen if the emissions intensity is between 1.5 and 2.5 kg.

The tax credit gets serious for emissions intensities below 1.5 kg. To be specific, it rises to US$1 per kg of hydrogen if the emissions intensity is between 0.45 and 1.5 kg.

Finally, it jumps to a massive US$3 per kg of hydrogen if the by-product emissions are less than 0.45 kg.

In summary, unless the blue hydrogen by-product emissions are 1.5 kg per kg or lower, it would not be worth producing blue hydrogen in the U.S. Published research from the Fenex CRC has shown that getting close to this is already feasible.[v]

Of course, each country will set its own thresholds for the allowable emissions intensity. However, it is possible that the 1.5 kg per kg threshold from the US Inflation Reduction Act will become a default target for blue hydrogen. The ultimate target of 0.45 kg per kg will be the BHAG – the big hairy audacious goal.

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Now, let's continue with how hydrogen should be exported. The answer is that there are many options.

When we developed the national hydrogen strategy four years ago, we were excited by the allure of Japan, Korea and other countries importing hydrogen and its derivatives. However, they have been slow to step forward. We all know that renewable electricity and clean hydrogen are key to the future, but the economics of clean hydrogen and how best to use it are not yet resolved.

If we use hydrogen to make ammonia for export, the ammonia synthesis process has to run on renewable electricity.

Similarly, if we export hydrogen as a liquid organic hydrogen carrier, or bound to a hydride, the hydrogenation process has to be zero emissions.

In all cases, the dehydrogenation process in the importing country must be low energy.

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The big shift in my thinking of late is to recognise the opportunity to use hydrogen onshore, to produce decarbonised products. The mantra becomes: *use it where you make it.* Effectively, this is a different way to export energy.

We have already been exporting embedded energy in our aluminium industry, given that a tonne of aluminum uses 15 MWh in the smelting process.[vi] Some people refer to aluminium as congealed electricity.

An opportunity to use hydrogen onshore that is drawing increasing international attention is hydrogen direct reduction to convert iron ore into green iron. This is a huge opportunity for Australia, because all steelmaking needs iron.

Steel itself comes in dozens of standard alloy mixtures, so producing steel for global requirements in Australia would be difficult. But all steel making starts with iron, and iron only comes in one form: iron is iron is iron.

So, making hydrogen-direct-reduced iron in Australia, where we have the renewable electricity and the ability to make the hydrogen cost effectively, is a huge value-add opportunity for Australian exporters.

Clean ammonia could perhaps be used as the reductant instead of hydrogen, and I am looking forward to one day learning the outcomes of the Fenex research into this possibility.[vii]

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Other opportunities for using embedded hydrogen and renewable energy to produce decarbonised products for export are green fertiliser for agriculture, e-methanol for international shipping and e-kerosene for aviation.[viii]

These liquid fuels deserve further discussion. Four years ago, when we developed the national hydrogen strategy, the predictions for the international maritime fleet were that it would shift from dirty bunker fuel to clean ammonia. But the giant shipping company Maersk said no to ammonia, and in August 2021 announced that it would purchase eight large container vessels to run on carbon-neutral methanol. This triggered an explosion of interest in methanol for shipping.

Today, the common way to make renewable methanol is from biomass. However, the only way to make truly carbon-neutral methanol is through synthesis using carbon dioxide captured from the air and hydrogen derived from water electrolysis.

The aviation industry is also investing in its future fuels. Two aeroplanes have flown this year with hydrogen-powered engines, both in the twenty to forty-passenger range. But the biggest interest is for carbon-neutral jet fuel to be used in existing jet engines for large, long-range aircraft.

Jet fuel is basically highly refined kerosene. Like for methanol, the common way to make a drop-in replacement for jet fuel is from biomass. The modern process, quite unlike the biodiesel of old, uses hydrogen treatment to remove oxygen from the biomass and increase yield.

The ultimate solution will be to produce synthetic kerosene, using carbon dioxide captured from the air and hydrogen derived from water electrolysis, all driven by cheap solar and wind electricity.

Given our abundance of sunshine and our proven large-project expertise, carbon-neutral methanol and carbon-neutral jet fuel could be huge future energy export opportunities for Australia.

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I often tell people that the biggest challenge for hydrogen is storage.

I drive a hydrogen car, a Toyota Mirai. It has excellent range: 600 km on a full tank. The reason is not the efficiency of the fuel cell or the electric motor. It is the high-tech storage tank that safely stores hydrogen at 700 atmospheres pressure. That carbon fibre reinforced tank is the unsung hero that makes the hydrogen car practical.

Cost-effective storage is critically important to the success of hydrogen, so I was pleased to see that one of today’s major conference themes is underground hydrogen storage, and that storage is one of the projects at the Kwinana Energy Transformation Hub.

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On a more subtle level, one of the things the energy export industry must consider is the role of incremental improvements versus going for zero.

No-one knows the answer, but when I look at what is happening overseas it seems that the strongest interest is to aim for zero. That is certainly the case in electricity generation, where zero-emissions electricity can be delivered by solar, wind, hydropower or nuclear power.

It appears to be the case for steelmaking, where the excitement is in zero emissions hydrogen-direct-reduced iron production rather than small improvements to blast furnace operations.

Going for zero is certainly the case for carbon capture. Tell somebody that the emissions were captured at the 60% level, and you will hear a tirade of complaints about the 40% that was not captured. Anything short of a 90% capture rate – measured over the whole of the annual production cycle – will be met with disdain.

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The important thing is that the transition to clean electrons and clean molecules should be seen as an opportunity, not an impost.

An opportunity for Australia to establish our credentials as not only a low-cost energy exporter, but one that produces those exports with the lowest by-product emissions. If Australia is smart, we can be part of the revolution. Fenex can show the way.

A key element in showing the way will be the Kwinana Energy Transformation Hub. It will be a proof-of-concept facility able to demonstrate how to optimise the zero emission LNG production process and how to unlock the promise of hydrogen.

The Fenex CRC is aiming high. Today's conference will help to ensure that you kick goals and improve the prospects for Australia's export industry.

May the Force be with you.

Thank you.

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[i] CATL unveiled its first sodium-ion battery in July 2021, https://www.catl.com/en/news/665.html

[ii] JAC and Volkswagen sodium ion vehicle, word's first, https://www.notebookcheck.net/First-electric-car-with-cheap-sodium-ion-battery-offers-157-miles-of-range-as-it-appears-out-of-a-VW-partnership.697298.0.html

[iii] Emissions of carbon dioxide per fuel type, https://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html

[iv] Lower heating value for hydrogen is 120 MJ per kg, thus 8.33 kg of hydrogen for one GJ. For the production emissions intensity to be 50 kg, would be 50/8.33 = 6 kg of production emissions intensity per kg hydrogen.

[v] Techno-economic and environmental assessment of LNG export for hydrogen production, Saif Al Ghafri *et al* (2023), https://doi.org/10.1016/j.ijhydene.2022.11.160

[vi] Electricity required for aluminium production is up to 15 MWh (although I have seen higher estimates), https://primary.world-aluminium.org/processes/power-generation/

[vii] Ammonia direct reduction of iron ore, https://www.fenex.org.au/project/project-2-direct-ammonia-reduction-of-iron-ore-21-rp2-0060/

[viii] Evaluation of renewable methanol at Fenex, https://www.fenex.org.au/project/a-technical-economic-and-environmental-assessment-of-clean-marine-fuel-options-and-industries-for-australia-22-rp4-0126/