The future of transport in a decarbonised world

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Introduction

We meet at a time of rapid, fantastic change.

Everywhere one looks new and emerging technologies are taking us towards bold new frontiers of imagination and innovation.

But there's a caveat.

For all the dizzying pace of change, the only true measure of a product's legacy is its lasting effect on future generations.

It must be impactful and beneficial, not merely exciting.

Failure to adhere to these criteria can result in the 'next big thing' becoming the 'next big flop'.

Remember 3D televisions, virtual-reality headsets, or Google Glass?

In preparing for this address, I set myself a challenge to measure current tech trends against this legacy test.

I started with cryptocurrency.

Is it impactful? No, if it disappeared tomorrow very few people would care.

Is it exciting? No, once the basic concept was defined it became a matter of doing the same thing again and again and again and again.

Is it beneficial? No, it is just another way for whiz kids to make money at the expense of everybody else. Score: zero out of three.

I asked myself the same questions of Artificial Intelligence. Score: two out of three.

And then, of course, I turned to transport, with a focus on the electric vehicle transition.

Is it impactful? Yes, it is forcing existing companies to modernise, and it is creating superstar new companies such as Tesla, Rivian and BYD.

Is it exciting? Electric car acceleration is literally breathtaking! I don't know any electric car drivers who would go back to their petrol-powered car.

Are electric cars beneficial? Absolutely. Not only do they provide incredible convenience to their owners, but they have the potential to fuel our long-term prosperity as well as preserve our planet.

Score: three out of three.

Members of the audience, whatever your role in transport research you are at some level, great or small, involved in the most remarkable technology revolution of our generation.

In coming together, each of you is exhibiting the hopeful spirit of humanity in the midst of a troubled and threatened planet.

We all recognise that the shadows of conflict and crisis lie heavy on the world today, with wars raging between Israel and Gaza, Ukraine and Russia, and the civil war in Sudan.

In contrast to the current world of geopolitics, the world of clean technology is booming.

Last year, for the first time in history, the global investment in clean technology exceeded that of fossil-fuel development – totalling US$1.1 trillion.

This year, it is on track to smash this number and exceed US$1.7 trillion.[1]

As a nation blessed with an abundance of all the ingredients needed to make clean energy, Australia has an unmatched advantage to be a world-leading electrostate of the future – exporting clean energy such as green hydrogen and jet fuel, decarbonised products such as green iron and aluminium, and most of the energy transition materials such as lithium and rare-earth elements.

But, to be a credible electrostate, we must transition to a near zero electricity system and then expand and build cleaner and cheaper electricity generation to replace fossil fuel combustion for transport, buildings and industry.

If you think of the net zero transition as a tree, the trunk is the clean electricity system of the future.

The lowest hanging fruit is the transport sector.

Other fruit within reach are building electrification and industry electrification.

Then it gets tricky because the higher up we go, the smaller and more difficult the fruit are to reach.

Those fruit are the emissions from waste decomposition, agriculture and chemical industries.

Although the transport fruit is big and within reach, that does not mean it is easy to grasp or digest.

But we know we can engineer it to a new variety.

The only question is how fast and how smart.

Which is why this Forum is so important.

With the transport sector being Australia's largest end user of energy, the vision and enterprise of this gathering can help us move forward, towards greater progress and achievement.

Predicting the future of transport

Despite the well-known maxim that prediction is difficult, I am going to share some thoughts about the future of transport as we continue the relentless push to decarbonisation.

Ideally, we would all utter the phrase "beam me up Scotty" to initiate zero-emissions teleportation.

Or we would all jump into our anti-gravity zero-emissions landspeeder like Luke Skywalker for our daily commute.

But, alas, we live in a world ruled by the laws of physics.

Yet, it is a world full of opportunity for scientists, engineers and entrepreneurs who can deliver alternatives to traditional transport that, in addition to decarbonisation, offer higher efficiency, lower up-front and operating costs, energy security, and minimal impacts on the existing logistics system.

Aviation

Let's start with aviation, always acknowledged as the hardest-to-decarbonise sector.

There are currently no commercial electric passenger aircraft, but the industry enthusiasm is contagious and more than 200 startup and existing companies have caught the design bug.[2]

Confidence is high, too.

Just this month I was in the United States, and, in the airport, I passed a poster showing an image of a United Airlines four-engine propeller plane emblazoned with the phrase "all electric" and a commitment to be operating commercially in 2026.[3]

Likewise, Israeli startup Eviation has developed a nine seater all-electric aircraft with a design range of 460 km at a cruise speed of 480 km per hour.[4]

It is attracting serious interest with a claimed US$4 billion of orders in May of this year – doubling its value of orders in just six months.[5]

German company Lilium has taken a surprising approach. Instead of using electric motors to drive a propeller shaft it uses electric jet engines.

Each engine is small, and the prototype has three dozen aligned along the wings. Lilium's first model will be a five seater, with a planned operating range of 250 km and a cruise speed of 280 km per hour.[6]

The obvious challenge is energy density. The best batteries are 500 watt-hours per kilogram.[7] That is tiny alongside the 12,000 watt-hours per kilogram of jet fuel.[8]

The other challenge is durability.

A study published this month from the University of Illinois predicts that because of the frequent charge and discharge cycles, batteries in six-passenger electric aeroplanes will lose 45% of their capacity in a year.[9]

Note, however, this estimate is based on today's chemistries.

If you are looking to make a contribution to improving battery chemistries for aviation, durability deserves as much, if not more, attention than energy density or cost.

What about hydrogen, which hold advantages over batteries in durability and range?

California-based company Universal Hydrogen recently stated that it has received its 250th order for conversion kits for the French ATR 72-passenger twin engine turboprop.

The conversion uses electric-motor-powered propellers running on electricity from a liquid-hydrogen fuel cell. Each order also includes a hydrogen-supply agreement at fixed pricing for ten years.[10]

Another company, ZeroAvia, has scheduled its 19-seater hydrogen commuter plane for commercial availability in 2025 with an initial range of over 500 km.[11]

While I cannot find a statement on the durability of hydrogen propulsion systems in aviation, there is no reason to think that it would be short.

When I visited the Ballard Power Systems factory in Vancouver in 2019, they proudly declared that their fuel cells have a mean time between failures of more than 30,000 hours.[12]

The flight range of liquid hydrogen aircraft is potentially high because it has nearly three times the mass energy density of jet fuel.

The business case has been compellingly argued by American engineer Chris Ellis.[13]

He takes the example of an Airbus A350-1000 that is loaded with 125 tonnes of jet fuel for a 16,000 km flight.

At 90 US cents per kilogram that is approximately US$110,000 dollars of jet fuel.

To replace the same energy content would require 45 tonnes of hydrogen.

However, because hydrogen reduces take-off weight and delivers higher efficiency in turbojet engines, Ellis calculates that only 33 tonnes of liquid hydrogen would be needed for the flight.

To match the price of jet fuel, the hydrogen would need to cost less than US$3.50 per kilogram.

If the hydrogen is locally produced for US$2 per kilogram, that would leave US$1.50 on the table for liquification, storage and handling.

Translation – it is well within the realm of possibility.

The challenge is to optimise the supply chain so that compression, liquification and storage costs are not excessive.

This should not be viewed as an obstacle, but as an opportunity.

It means there are lots and lots of avenues for innovation stemming from more and more research.

And long distance aviation adds to the use case for the Australian hydrogen industry.

There is also growing interest worldwide for drop-in replacements to jet fuel.

Today's jet fuel is basically highly refined kerosene. With just a little bit of heating, it doesn't freeze when an aeroplane is cruising at -50°C nor does it boil when it is taxiing at +50°C at Dubai airport.

Contrast that with conventional biofuels which, aside from carrying impurities, start to gel at temperatures of around zero degrees Celsius.

Fortunately, science has provided a solution in the form of hydrotreated vegetable oils, or HVOs.

As the name suggests, HVOs are produced by using hydrogen instead of methanol as the catalyst.

This process makes a biofuel that is virtually indistinguishable from fossil-derived jet fuel while reducing carbon emissions by up to 90% and yielding up to 50% more fuel per kilogram of biomass than conventional biofuels. [14]

And, as the hydrogenation process removes oxygen from the fuel, there is also significantly reduced risk of degradation and oxidation.[15]

Currently, the world market for modern biofuels is dominated by a company named Neste with its plants in Finland, Holland and Singapore.

Australia has biomass and we can produce cost-competitive hydrogen, yet we're not on that list.

This is not only illogical, it is an affront to Australia's legacy of enterprise and achievement.

It is an opportunity we can and must seize.

The other big opportunity for Australia is fully synthesised kerosene, for aviation. No biomass required.

I call it Ancient Greek jet fuel.

The Ancient Greeks believed that there were four elements: earth, air, water and fire.

Taking solar electricity as synonymous with fire, we can use it to separate hydrogen from water.

We can use more fire to capture carbon from the air.

And with even more fire we can combine the hydrogen from water and carbon from the air to synthesise kerosene.

And there you have it. With just three of the four elements – air, water and fire – we can make modern jet fuel.

It is absolutely carbon neutral.

It is a dream that that is too expensive today but is ultimately the only truly carbon neutral pathway for jet fuel.

Perhaps you will be part of the team that converts it into a cost effective reality.

Shipping

Turning now to shipping.

At the small end, solutions are in hand. My wife and I were in Copenhagen last month and enjoyed a tour of the canals on a battery powered, eight-passenger boat.

The silence of the drive meant we could hear our tour guide with ease, but what particularly impressed me was that the boat was on its fifth one-hour excursion for the day and the battery was still nearly fully charged.

We never went above about six knots, but it was perfect for its designed operation and much better than the diesel it replaced.

For larger ships, some futurists are investing in wind-assisted cargo ships using vertical wind sails, but these only provide incremental improvements.[16]

More realistically, it is a battle between green ammonia and bio-methanol.

In the near term, big fleet operators such as Maersk are turning to bio-methanol, but they all have a declared commitment to using ammonia in the long term.

The advantage of ammonia is that it is truly zero emissions if made from green hydrogen and a renewable energy powered synthesis process.

Countering this are several disadvantages – cost, logistics, NOX emissions and toxicity. These can be overcome, but it will take time.

There are obvious research opportunities around cost effectiveness, zero emissions ammonia synthesis, and engine design.

Terrestrial

The third sector, the biggest emitter and the one dearest to our daily lives, is terrestrial transport: cars, trucks, trains and mine-site vehicles.

The progress towards adopting battery electric drives is nothing short of stunning.

Off a very low base, electric car sales in Australia have been accelerating for the last three years and new car sales in September broke through the 10% barrier.[17]

This rapid growth is happening even without a national fuel emissions standard. It is being driven by several factors, not the least of which is consumer power.

Consumers want to drive zero emissions vehicles. Consumers want to drive high performance vehicles. Consumers want the incredible convenience of charging at home. Consumers want low cost, infrequent service. And consumers want the much lower cost of electricity per km driven compared with petrol per km driven.

One of the best indicators of wider adoption in Australia is that we now have three electric cars that are under $40,000 while delivering over 300 km driving range in their base models.[18]

Range anxiety is fast becoming a distant memory. My first electric car, which I purchased ten years ago, had 150 km range; an upgrade that I purchased in 2019 had 240 km range; my most recent purchase this year has 450 km range.

I predict that by the end of the decade, premium performance cars will have 1000 km range. Standard performance cars will be at least 500 km.

These increased ranges will not only give comfort to the driver but will also reduce the needed number of public-charging facilities.

Something that the engineers among you might want to tackle is the reliability of public quick chargers.

For reasons I do not understand, on the few occasions I have needed public charging, about half of them were out of service.

In one instance, there was not a single operating charger and I had to limp to another location.

It should not be difficult to design solid-state electrical systems to run reliably! Smartphone manufacturers have worked it out.

Turning to mining vehicles, I visited a copper mine in Salt Lake City in the United States last month and watched massive trucks hauling 350 tonnes at a time up and down a steep slope constantly for 12 hours.

Alarmingly, none of the mine's staff had any expectations that they would see battery electric haul trucks in operation anytime soon.

Luckily, back home, our miners in the Pilbara are testing prototypes of battery electric haul trucks and battery electric trains, although these demanding applications face challenges of range and durability.

For consumer trains, battery power might be the breakthrough that makes it easy to replace diesel locomotives. Electrification is probably cheaper and a well used existing solution. However, it is not always practical.

For example, in some parts of Germany they have been unable to electrify their train tracks because of the prohibitive cost of retrofitting overhead power lines in the numerous tunnels and bridges.

In these cases, the plan now is to electrify the majority of the train line and use small onboard batteries to cruise through the tunnels and bridges.[19] Problem solved.

Hydrogen cars

What about hydrogen-powered cars?

I am probably the only person in this room who owns and drives a hydrogen-powered car. The car itself is brilliant. It is a second-generation Toyota Mirai. It has 600 km range using a fuel cell to drive the electric motors and it has the wonderful responsiveness and smoothness of an electric car.

Nevertheless, it mostly sits idle in my garage. Why? In the first two years since I bought it the number of refuelling stations in Melbourne increased by precisely zero.

There are only a handful in the whole of Australia.[20]

Although it takes fewer than five minutes to fill the tank with hydrogen, it is a 30 minute drive to the refuelling station from where I live, meaning it takes over an hour of my time to refuel.

The alternative is 15 seconds to plug in my battery electric car in the evening and 15 seconds to unplug it in the morning.

But my attitude is on the cusp of changing.

Victoria doubled the number of refuelling stations last week from one to two, with the opening of a refuelling station at the CSIRO campus in Clayton, in the south-eastern suburbs of Melbourne.

It was a grand event with politicians and dignitaries. Most important, I got to drive up in my car and be the first person to be refuelled at this new station.

I often drive to or near Clayton, so all of a sudden refuelling might not be such a nightmare. Please check with me in a year.

But that is still only two hydrogen refuelling stations for the whole of Victoria, and both of them are on private land and only accessible 9 to 5. The summary is that the logistics of hydrogen refuelling are terrible.

If you are involved in the industry, think about refuelling station designs that will be much cheaper, use much less real estate and be much more reliable that what is currently available.

And think about use cases. Hydrogen refuelling will probably work best for return-to-base, heavy-use commercial vehicles.

System logistics

The logistical advantage of batteries over hydrogen for vehicles is that batteries do not need a whole new supply system. All that is required is an upgrade of the existing system.

Even with the explosive growth in new electric car sales it will still take more than twenty years for the fleet of vehicles to become substantially electric, so this will be a gradual process that should be well managed if the research and planning is in place.

But the current excise tax on fuel is something that Governments will eventually need to replace.

Victoria made a start by collecting a mileage-based charge, but it was too early, sent a negative message to early adopters, and was recently outlawed by the High Court because excise taxes are the province of the federal government.

A useful question to be answered by social scientists is the timing for bringing in a road-user charge for electric vehicles.

A useful question to be answered by economists is how road-user charges should be determined. The obvious way is to charge based on the combination of kilometres driven and vehicle weight, but there might be other models that would be even better.

Supply chain

Turning to the supply chain, will we ever run out of the materials we will need?

That is, will we eventually strike peak lithium, peak nickel, peak cobalt?

The same question has been asked of oil for five decades, but peak oil as a production-side limitation has never occurred.

The reason is captured in a single word: innovation.

Suppliers developed deep sea drilling, horizontal fracking and enhanced oil recovery.

I predict the same on the electric vehicle supply side. If lithium, nickel and cobalt continue to be expensive because of constrained supply, manufacturers will replace them with alternatives.

We are already seeing it happen.

In the last three years, lithium ferrous phosphate formulations have captured 30% of the EV market. No nickel, no cobalt.

Starting this year, sodium-ion batteries began entering the market. No nickel, no cobalt, no lithium.

There are trade-offs, such as reduced energy density per kilogram, but those trade-offs don't look nearly as bad today as when the sodium-ion batteries were in the lab a decade ago.

Recycling would help to alleviate the supply constraints. In some cases, it already works well. Because copper, aluminium and steel are mostly recovered as big lumps, they are easily handled by the recycling process.

But recycling battery metals – lithium, nickel and cobalt – is much harder because separating them out requires grinding and multiple chemical washes, creating problems associated with high energy use and waste management.

Working out how to recycle spent electric vehicle batteries will be an important challenge for scientists, engineers and regulators for decades to come.

A short term solution is to safely and efficiently re-use battery packs that will become available in seemingly random sizes, chemistries, voltages and capacities.

An example currently being tested is a clever technology from Toyota, called the Sweep Energy Storage System.

It enables a mix of batteries, salvaged from electric vehicles, to be connected in series in three strings and converted into a three phase AC output ready to connect to the electricity grid.[21]

Two maybes

Okay, now it is time for a couple of 'maybes'. Each of these technologies has been on the cards for at least the 13 years that I have been actively involved in the electric car industry.

The first is vehicle-to-grid, commonly known as V2G.

The potential is huge. If we get to the point of having 10 million cars in Australia with batteries of about 100 kilowatt-hours each, that would total 1000 gigawatt-hours of storage. If half the drivers participate and no battery is drained more than 50%, that would still be a massive 250 gigawatt-hours.

That is almost as much as Snowy 2.0, without the need to build new transmission lines or deal with social and environmental impacts.

Let's imagine that those 10 million cars all have home chargers. That is a cost the owners have to bear, so no public cost there.

Next, we install 10 million additional chargers in building car parks and kerb-side parking.

And let's assume that somehow there is perfect utilisation and that those 10 million public chargers are enough.

Let's further imagine that those 10 million additional chargers are low power and cost about $3000 on average for supply and installation.

That's $30 billion.

Sounds like a lot, but it is not much more than the projected cost of Snowy 2.0 when the transmission line costs are included. Assuming useable storage of 250 GWh, that comes to $120 per kilowatt-hour.

That is cheap compared with current battery costs.

Nevertheless, I am not optimistic.

My main concern is that it is difficult to see how enough money could be offered to incentivise people to plug in whenever they are parked.

Let's say everybody was paid $300 per year to participate. For 10 million drivers, that would add $3 billion per year to the total cost of electricity, corresponding to a bit over $11 per megawatt-hour.

Perhaps that's acceptable from the system point of view.

However, from the driver's point of view, $300 per year is only 80 cents per day, less than a fifth of the price of a cappuccino.

For that, drivers would have to deal with the inconvenience of plugging in perhaps five times per day.

My own experience driving electric cars for more than ten years is that I charge about once a week. I love that hassle-free existence and I could not be persuaded to plug in five times per day by the promise of a cappuccino every now and then.

Something tells me that there might be more drivers like me than desperate cappuccino addicts.

Of course, those of you in the audience who are working on V2G, I hope to be pleasantly surprised by your success.

The second 'maybe' technology is wireless charging.

I've been reading about wireless chargers for 15 years, but it is now 2023 and I have never seen one, nor heard of anybody who owns one.

The problem is that they are lossy, very expensive to install, and require precision parking.

In short, what works for a smartphone does not necessarily work for a car.

My overarching concern is that when a good idea has been around and tried for a long time but has not made significant inroads, there is probably a reason.

For instance, wave powered electricity generation, tidal power, and hot rock geothermal have all been actively tried for decades, but their combined net contribution to global electricity is inconsequential.

Generative AI

The known unknown hovering over everything is generative AI.

I call it known, because it is everywhere and growing rapidly.

I call it unknown, because it is impossible predict its impact in even a couple of years when it is so incredibly powerful, growing scarily fast, and effectively unrestrained.

One simple use of generative AI in transportation, which has started to appear in the last few months, is itinerary planning. Expedia has a product called Project Explorer that customises trips based on budget, location, time of year and interest.[22]

But that seems trivial compared to the use of generative AI in aircraft design.

With generative AI, engineers specify the design parameters and constraints, press the button and the AI generates a suite of design options.[23]

Never tiring, the AI then analyses these design options for their aerodynamic performance, fuel efficiency and safety.

Generative AI has an increasing role in predictive maintenance, and training and simulation.

It can even save airlines time and money by analysing historic and real-time flight, weather and air traffic data to recommend more fuel-efficient and time-saving routes.

Nevertheless, one of the major issues with generative AI is that it is prone to hallucinations.

That's fine if it is generating design options that will later be evaluated; but concocted answers would be a disaster if AI were to be used to schedule take offs, landings and taxiing on the tarmac.

Autonomous vehicles

I cannot finish without talking about the adoption of autonomous vehicles.

It is proving to be much harder than was thought by the prognosticators who predicted that autonomous vehicles would be common by 2020.

Instead, there are just a small number of trials underway.

The most prominent is the Cruise and Waymo trial in San Francisco. Cruise, a company owned by General Motors; and Waymo, a company owned by Google's parent company.

In June of last year, Cruise received California's first Driverless Deployment Permit, allowing it to charge fees for its service, just like Uber.

After operating its fleet of 100 robo-taxis for a year, Cruise's self-driving permit was suspended last month after a series of safety incidents, including a particularly gruesome event in which a pedestrian was dragged 6 metres after the car stopped then tried to pull over to avoid traffic.[24]

It was a rare event, but autonomous vehicles are and will be held to a higher standard than human drivers.

The reality is that operating an autonomous vehicle is incredibly difficult.

Not only do the vehicles require flawless algorithms, but they also need to be able to talk to each other and to the city traffic control system.

They need precision proximity detectors such as lidar, however lidars don't work in rain and snow.

They need GPS that works even in the deep valleys between city skyscrapers, and in tunnels.

The toughest challenge of all is that they need to be able to share the road with other vehicles driven by unpredictable human beings.

Some experts I have spoken to say it is too hard and that fully autonomous fleets might never be realised.

But I firmly believe that scientists and engineers such as yourselves will solve all the technical problems, it's just that the problems are proving to be harder than anticipated.

One last problem. Fully autonomous vehicle fleets might create more congestion, not less. Autonomous is not synonymous with shared or publicly owned.

Let's take the example of a single autonomous car, privately owned by Bob and Alice.

If that car takes Bob to work, then comes home to take Alice to work then returns home to park rather than pay city parking rates, that's four trips.

In contrast, there would only be two trips if Bob and Alice each drove their own car to work.

Such issues will need to be modelled in order to guide policy development.

Concluding remarks

None of these future scenarios will be easy to accomplish.

They will test the limits of our skills and innovative spirit.

But through this Forum we see how progress happens – individuals coming together to dream and plan our next steps.

I am excited to see in coming years the creative and resourceful solutions you will devise to deliver the most exciting, impactful and beneficial technological revolution of our generation, for the benefit of future generations.

May the Force be with you,

Thank you!

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