ChemEng Evolution - Transcript Summary
Past President John McGagh talks to Dr Alan Finkel

Finkel was educated at Monash University, receiving a doctorate in Electrical Engineering in 1981. He then served as a postdoctoral research fellow at the Australian National University, before leaving academia to found Axon Instruments, a global science and technology company based in the US. During this time, he invented a commercially successful device that substantially speeds up pharmaceutical drug research.

Since then, he has used his wealth to found the science magazine *Cosmos*, an environment magazine called *G: The Green Lifestyle Magazine* and contribute towards a number of research institutes. During a speech at Monash University's 50th Anniversary Celebration Dinner, he announced that he would be endowing a Chair in Global Health for the University.

After eight years as Chancellor of Monash University, he served as Chief Scientist of Australia from 2016 to end 2020 leading, amongst other achievements, a review of the future of the Australian national electricity market. In 2006 Finkel was appointed a Fellow of the Australian Academy of Technological Sciences and Engineering (FTSE). In 2009 Finkel was appointed as the Chief Technology Officer of Better Place Australia. In 2012 he co-founded Stile Education, a science education company based in Melbourne, Australia. In 2013 he was appointed President of the Australian Academy of Technological Sciences and Engineering (ATSE). Since 2011, Finkel also serves as the Patron of In2science and since 2013, as the Patron of the Australian Science Media Centre. In 2022 he was appointed Companion of the Order of Australia (AC), the highest civilian award in Australia.

Key messages/themes.

- AI will impact humankind in ways we cannot yet predict. We will be faced with interacting with AI systems in a pervasive manner that will be profoundly more capable that humans in ways we are yet to understand, we need to develop a balance in this emerging “relationship”. Not to be feared but to be managed.
- Climate change is the pressing challenge of our time, we need to find the technologies that help us combat this threat through carbon reduction. Chemical Engineers have a very large role to play, this is their challenge of the century. This could be the most exciting technological time since the space race.
- Aviation decarbonization is tricky. We may have to accept a form of hydrocarbon fuel to power transcontinental air travel. Batteries and hydrogen will manage short and medium haul routes.
- Biofuels are not a hydrocarbon replacement opportunity. To power say 50% of the Qantas domestic fleet would need a land mass the size of the state of Victoria to provide the bio feedstock (Victoria is approximately the same size as the UK)

- When we think about net-zero, developed economies need to count the carbon in the goods they import. Many advanced economies have outsourced manufacturing, and this has given them benefit in terms of their carbon footprint.
- Hydrogen is not a primary energy source; it is a secondary energy storage and transportation vehicle. We need renewable energy or zero emission (e.g., nuclear) sources to produce hydrogen, not insolvable but a large challenge.
- Primary energy from coal, oil, and natural gas, for electricity generation, transportation, and stationary energy (heating, manufacturing etc.) make up 72% of Australia's carbon footprint, with another 10% coming from the fugitive emissions associated with coal and gas. By full electrification using renewables and the eventual weaning of the rest of the world from our coal and gas exports, we can dramatically reduce our emissions.
- The remaining 18% is hard, with waste decomposition, agriculture, industrial product, and land use being significant contributors. Chemical Engineers can play a very large part in reducing the "very hard" 18%. It may be 18% now but we electrify our energy system these hard to abate sectors will become an ever-larger percentage of our total emissions.
- Animal enteric emissions are significant. There is optimism that feedstock additives will significantly reduce methane emissions from cattle and sheep. The digestive chemistry in ruminants is complex, and there is much yet to be learned about chemical interventions and 'natural' interventions (using seaweed extracts). Ultimately the methane forming bacteria in the animal gut have to be disabled, but it is not clear whether it is a biological challenge or chemical engineering challenge. Of course, it is both.
- Low carbon fertilizers produced from renewable ammonia or other means have a part to play, Chemical Engineers have a big opportunity here.
- Circular economy, including non-hydrocarbon feedstock (plastics and other chemical derivatives) using for instance biotechnology derivatives is also an opportunity.
- The big challenge will be to recycle and create a closed loop system, this is Chemical Engineering on steroids being applied to waste.
- Practical carbon capture and storage is a very important technology.
- Direct Air Capture of CO2 is thermodynamically very hard, we should look at this but be realistic as to potential.
- A range of governments are trying to drive the whole solution thinking forward for the Glasgow COP21 meeting. They want to define pathways rather than just develop statements of ambition. Now they want, say, five clear challenges that will make a difference. This is way I've been feeling it, rather than seeing it of late.
- I still think of the 1960s as technologically, the most exciting decade of my life. Because we had the exploration of inner space and outer space.
- Then we had another era, with electronics and personal computers. In about 1990 through 2000's we stopped talking about hardware and start talking about all the things you can do on the Internet such as social media – we became connected.

- In this decade we are seeing renewable technologies just leaping forward. This could be the most exciting decade in the last fifty years, one in which the Chemical Engineering community will deliver societal benefit, you should look forward to it and embrace it.
- I think about the three most incredible elements in our pursuit of technology, Hydrogen, Silicon and Lithium
- **Silicon**. Has powered computing AI which is shaping our world (it is also key to the solar PV energy revolution)
- **Lithium**. The lightest metal it is only the third heaviest element, with the largest electrical potential, so the energy ratio is the best.
- **Hydrogen**. when it comes to fuels, hydrogen is pretty magic. It's the number one element. No nasty byproducts.
- Perhaps Silicon is King, Lithium is Queen and Hydrogen is Supreme.

Narrative – abridged from original digital transcript

I have looked at your themes to 2100 and will cover them in no ranking order, starting with the premise that Technology will dominate our future and that digital technology will dominate our lives.

Starting with transport, of course, it will be very different. I don't buy the Jetson type of stuff with flying cars and things like that. I know there will be certain city-based flying via individual Uber type helicopters (drone concept), but they'll never be dominant. Importantly, all ground and sea transport will be zero emissions. We transport a lot of people and goods around the planet so eliminating the emissions in the transport sector is important for our low carbon future.

So, what will it be thinking about mass transit? INo one will actually put their foot on an accelerator or hold the steering wheel probably ever again after about 2050.

But much more significant than this will be the relationship with the digital technology as it will be increasingly serving society, and like all servants, has to be well treated so that it doesn't rise up and rebel against us.

Not that I think the digital technology really will rise up and rebel, but we need to think about an equitable balance with machines that will leave us with the dignity that helps deliver what we want in life.

Soon we will be being assisted by something (i.e., AI enabled systems) that is so much more profoundly more capable than us (humans) in terms of almost anything, these are really difficult challenges and I have no idea how they will evolve.

I am confident that as we have been used to saying, humankind will solve the problems as we go; I personally do want this to happen. I'm not a doomsday person, but the transformation that AI will drive is essentially just too big to imagine.

From the point of view of the Chemical Engineering supporting Society I would think that the single most important thing for the next 50 years is playing an important part in driving a transition to a zero-emission society.

We just must do this, yes, I use the phrase zero loosely.

John, I don't use it in the mathematical definition of meaning which would be nothing, zero in my mind just means close to nothing. So, using this thinking a zero-emission society will never be mathematically zero-emission, but much, much less than what we've got now. There is a scenario that when we include offsetting mechanisms it might be net-zero, indeed.

But this transition is going to be so much harder than people tend to think it's. Net-zero is probably practical in the next 30 or 40 years for the advanced economies, but that is partly because they've offshored huge fraction of their industry. Illustrated by looking at the incredible decline in emissions that the UK has achieved, this is much less impressive if you correct for the cuts due to offshoring manufacturing and other carbon intensive industries. Much more accurate if you look at emissions associated with the goods that they consume, in which case the picture does not look anywhere near as good.

Much of what we consume is being manufactured in China and countries like it. We have all seen President Xi Jinping committing China to a zero emissions economy by 2060, but I find it very hard to believe as the challenges for China and the World are huge.

And the obvious solution is replacing our use of fossil fuels to the maximum degree with electricity sourced from renewable sources, this is when we talk about the electric planet. Obvious but hard.

But electrons (electricity) are only useful to a finite extent, maybe they could support 70 or 80% of everything that we need. We do need a transportable high energy fuel; hydrogen as this fuel obviously comes to mind but using it efficiently and effectively across all of the economy is not easy.

I am covering this in this essay that I’m writing for the quarterly essay (standing Australian publication).

I point out if you just take the Australian economy and break it up by sectors as reported by government, the three biggest sectors for this discussion are electricity generation, stationary energy, and transport.

Electricity generation is self-evident, and you know what I'm talking about.

Less obvious is stationary energy, this is energy used for heating buildings and hot water and things like producing steam in industrial processes.

Transport is what it says, transportation; today all three of these depend on fossil fuels, a very high percentage of fossil fuels are used for energy rather than elsewhere in our economy.

So, all the use of fossil fuels for energy, not as a chemical feedstock, appear in those three sectors and these are large carbon emitters.

The 4th sector that fossil fuels have a significant contribution with respect to carbon comes from their fugitive emission, of course, fugitive emissions are just associated with producing natural gas and coal. We can tweak them and improve them to some extent as we go forward. But for Australia, fugitives will intrinsically go away as the rest of the world stops buying our coal and oil. So, if you do the numbers 72% of all of Australia's emissions from those first three categories of electricity generation, stationary energy, and transport, 10% is in fugitive emissions, which adds up to 82% of our emissions. These be addressed by replacing fossil fuels for energy generation.

Consider electricity or products made from electricity such as hydrogen and of course this allows for the distinction between fossil fuels and say hydrogen.

Like hydroelectricity and nuclear, fossil fuels are primary energy sources. Hydrogen is a secondary energy source; it is an energy transport mechanism and people mix up this important consideration.

You must use a primary energy source, could be solar, electricity or wind electricity to generate hydrogen. But then, once you've generated hydrogen it is a transportable fuel, and this is very useful and important.

Hydrogen can be “clean” if it comes from fossil fuels with carbon-capture and storage (CCS), or from renewables. It will probably come from both, with the majority coming from renewables. The combination of clean hydrogen and clean electricity will dramatically reduce our direct emissions, but after that it gets hard. That last 18% of carbon centric emissions remains to be tackled and I can’t see the pathway yet.

So where do we look for the last 18%? I see some important sectors and these cover land-use (agriculture) and Industry – chemicals fit in with Industry.

This is a really hard problem and that’s where I think chemical engineering needs to come in because chemical engineering understands process at scale and can address the underpinning systems within the remaining 18% some of which is fossil fuels being used as chemical feedstock.

Significant emissions come from the carbon dioxide emissions from cement. Making cement is via the clinker process where you take the calcium carbonate and turn it into lime. Intrinsically, that process gives off significant amounts of carbon dioxide. We need alternatives.

Could be via the geopolymer cements or whatever alternates we develop but we do need these alternatives. Cement depending on where you get the statistics is responsible for between 2% and 8% of global emissions. I haven't got a clue what the true figure is. I think it's probably closer to two or three percent, but it's a lot and it will be proportionally a lot more once we've cleaned up the other 82%.

Also, chemical engineering must find a way to replace fossil fuels for the plastics that we consume. When I say chemical engineering, I mean a sort of large-scale industrial engineering.

These are things that chemical engineers of this world must tackle, these are big problems and I see this as a huge opportunity for the profession and they're not simple they are hard. Take agriculture we must find a way to make zero emissions fertilizers.

Assuming the energy industry will provide zero emissions hydrogen the current production process has to be replaced by a zero-emission process.

This will happen across all the production economy; chemical engineers have a big opportunity. Just look around us and think how we produce all of this “stuff” (steel, carpets, buildings etc.) with zero emissions processes,

And the big challenge will be to recycle and create a closed loop system, this is Chemical Engineering on steroids being applied to waste. We are not going to solve the problem purely by training people not to create waste as it is just intrinsic to modern society. You’re not going to solve it only by having biodegradable packaging, although biodegradable packaging is a good start and depends on chemical engineering.

I have conducted a home experiment. If you buy some plastic rubbish bags labeled biodegradable, test them and you will find they're not biodegradable. I took some a couple years ago, I put them in a container on my balcony in sunlight with water and air vents for over a year. I took them out, two of them hadn't changed at all – not biodegradable in this simple experiment. One of them had a little hole, and yet there are other bags that we buy which are made from sugar cane and I'm sure they're biodegradable because by the time you get home from the supermarket, things are falling out of the bag through holes at the weak spots. A challenge and an opportunity.

These are not easy challenges, I think that the chemical engineers of the world should also do the non-sexy essential challenges, in doing so they're going to make the non-sexy essential contribution to that final 18%, and partly it'll be in in in agriculture.

Everybody thinks about solar and wind and batteries as being the only thing that matters, it is not that simple. You don't get the hydrogen here, but with a renewable or zero carbon energy source now you've got hydrogen feedstock and then some of the challenges remain staggering such as Aviation fuel. What are we going to do about aviation fuel, that's a tough one?

Airbus has committed to building hydrogen fuel options. Airplanes have essentially three different designs for 2035.

One category will be able to do cross country, so there will be 200 passengers up to say 4,000 kilometers (Melbourne to Perth) which is going to require high density liquid fuel, may be hydrogen. This demands way more than you can expect to get out of a battery powered or electric plane battery.

Electric planes will take say 100 people from Melbourne to Sydney (less than 1,000 km).

Airbus can see a solution to the above, but they haven't got a solution between 4,000 and 12,000 kilometers which covers the long-distance transcontinental flights.

Thinking about aviation fuels you get all the very clever people saying we use biofuels. Then you speak to people who've done the numbers like David Norman from the Future Fuels CRC, he says for Qantas to operate its domestic fleet on biofuels you have to plant the whole of Victoria with palm trees for palm oil, sorry it was for 50% of the Qantas domestic use., It's a staggering amount, so biofuels are not the solution, even though they might be part of it.

And then you get people saying, OK, we need synthetic aviation fuel. Combine molecules with clean hydrogen and make methanol and derivatives, a possible pathway.

It's a real stretch goal and it may be that we give up and we always accept that long distance aviation will be running on kerosene, and we must do offsets by sequestration.

But if we can solve it at source, of course, that's much better than doing the offsets. Globally pre-pandemic aviation itself is growing 4 or 5%, and as the rest of the easiest sectors to deal with for the economy are decarbonized, aviation would just come a bigger and bigger percentage of what remains.

Another route to decarbonize the ecosystem is to use Direct Air Carbon Capture and Storage (DACCS) but this is very hard indeed if you think about the numbers.

To do direct air capture, you must have very large fans to move air over capture mediums. It's the inverse of wind turbines. We use big wind turbines to generate electricity not to direct air capture.

You must have big fans to blow the air across membranes where you've got a process within the membranes to capture the carbon dioxide. Consider the mass of every single air molecule, essentially pumping 2500 air molecules to bring one carbon dioxide molecule to the membrane as it is only 400 parts per million, then you must remove, and those laws of thermodynamics tend to be pesky. You must modify the rules of thermodynamics! Not really, they've frustrating you know!

We must find a way to process manure so that it doesn't decay and emit methane via the aerobically methane pathway.

Australia CSIRO, New Zealand, and American researchers are working on trying to deal with digestive methane emissions from cows and sheep by sort of "poisoning the poor cows" by feeding them compounds that will destroy the methanogenic bacteria in their stomachs. Optimizations will come from processing the feedstock. Somehow the cow survives, not only survives, but thrives. It grows faster than normal. It is surprising. You assume that there was an evolutionary purpose in selecting methanogenic bacteria; if you are suddenly going to knock them out and they're have an important role, such as breaking down otherwise indigestible lignin and cellulose walls, it is surprising that this is not harmful. And it isn't. Is this approach a biological challenge or chemical engineering challenge? Of course, it is both - I just see an enormous opportunity for chemical engineering as part of our transition to zero emissions. In the case of New Zealand, they are developing vaccines. You know methane is around about 18% of all greenhouse gases at least half of that comes from cows and sheep enteric fermentation, so it's a big deal and it really has to be tackled.

Another solution is to replace grass with other feedstocks that cows can eat that don't have the same composition of lignin cellulose. You and me being members of the human-race John, we can happily eat lettuce and broccoli but not grass and tree leaves, that is the way we evolved

The other course is just getting rid of real meat and bring in another source of protein. You won't be able to say synthetic meat just like you can't say sparkling wine is champagne. If you buy some soy milk now, I don't think you'll see the word milk on the carton it will just say Soy. So, it won't be called synthetic meat, it will be synthetic, high density protein food. I think they'll make it so well that people will in the main, enjoy it, they'll synthesize the flavors and textures of fish and meat, but we have a way to go. I've tried a few of them, but they're not there yet. I have not been able to find anything that was supportive of the statement that the life cycle carbon dioxide emissions of synthetic meat are lower than the life cycle greenhouse gas emissions of real meat, or we have to prove that it's not before we move forward. I think eventually it will be, and that's a big challenge not just for biotech people, but for the chemical engineering fraternity, this has the potential to be a large at-scale industry and chemical engineers have a part to play.

To enable the transition to zero emissions we will probably need hydrogen as a reductant in iron and steel, also cement manufacturing. Other iron and steel process routes like electrolysis, as used in aluminum production, can be investigated. To achieve net zero emissions, we will have to look at all options that have a scientific basis.

Big question to be answered to enable this change - <u>is carbon being costed?</u>

We're still seeing an accelerating rate of change in commitment. But targets are not enough. The Australian approach is not seen as consistent with international aspirations, but we are developing and deploying low emissions technology to provide solutions. Ours is a low emissions technology driven pathway, and it is delivering results.

The philosophy is very simple.

The government is identifying high abatement, high economic value technologies as priorities, where government influence will make a difference to drive them down the cost curve. The idea is to get to cost parity with that of high emissions alternate incumbents at which point, you're at a tipping point and everybody's buying the low emissions technologies. This can be achieved and that can be achieved without carbon taxes. But it does require direct government investment into helping the newcomers move down the cost curve.

Economists in the Australian Liberal Party would prefer to do that rather than increase the cost for everybody including the incumbents by implementing a carbon tax regime.

As a country we have played with the tax route before. I think so far about four party leaders and prime ministers have lost their jobs by trying, so it's unlikely to come up again soon.

A range of governments are trying to drive the whole thing forward for this Glasgow meeting. They want to define pathways rather than just develop statements of ambition.

I was a teenager in the 1960s. I still think of the 1960s as technologically the most exciting decade of my life. Because we had the exploration of inner space and at the same time the exploration of outer space triggered by the launch of Sputnik. I followed the Mercury program, every single one of those launches. I followed the Gemini program and the Apollo program. I couldn't wait to get my National Geographic magazine, which would have the spectacular-colored pictures of Jacques Cousteau during his exploration of inner space up to 5 kilometers deep in the Pacific trenches, it was so exciting. Then we had another era, with electronics and personal computers. Then things got boring for a techie like me in the 1990s and the 2000’s because everything was about the internet and social media, so I used to focus on the computer world.

But <u>this decade</u> we are seeing renewable technologies just leaping forward. This can be the most exciting decade that the Chemical Engineering Society should look forward to and embrace.

I wish to close with a sort of retrospective I think about on the three most incredible elements in our pursuit of technology

1. Hydrogen
2. Silicon
3. Lithium

Silicon. I have been an electrical engineer for all my life and read many articles about alternatives to silicon for microprocessors, such as germanium, DNA, proteins, optical components, and others. And all the while, there have been predictions that Moore’s law would come to an end.

While people were talking about these alternatives, Silicon microprocessors just kept on getting better and better and more powerful. Moore's law doesn't run out for humanity because Moore's Law is a measure of ingenuity, and ingenuity is an unlimited resource.

Lithium. When it comes to batteries the lead chemistry will always be based on lithium. It's the lightest metal, it is only the third heaviest element, and it has the largest electrode potential, so the energy ratio is the best.

Hydrogen. And when it comes to fuels, hydrogen is pretty magic. It's the number one element. No nasty byproducts when it burns.

I wrote a Cosmos article called Silicon is King. Another Cosmos article called Lithium being Queen. I also wrote an article on Hydrogen, but I didn't get a good title for it.

Maybe hydrogen is Supreme.

There is something very special about these three elements. There are other important ones too, but I'm not sure the top three will ever be dislodged.