1 Good evening everyone. My name is Carol Holden and this is Hugh Bridge. Our talk today is titled:

A storage solution for clean energy

World-wide over the last few years, most people have come to realise that fossil fuels are harming our environment and there is an urgent need to move to clean energy. Most clean energy is by nature intermittent – when the sun don't shine and the wind don't blow, the power don't go. So, if we're going to use clean energy to replace fossil fuels there needs to be an affordable way to store it, transport it, and export it.

Our presentation today outlines how Hydrogen and Ammonia can achieve that goal, AND provide endless jobs now and far into the future.

2 Renewables

World-wide production of renewable energy is growing at an ever-increasing rate. Some well-known renewables are:

Solar power, Wind power, Hydro, Geothermal energy, Wave power

And as always Fusion – only 10 years away. Just as it has been for the last 50 years.

These renewables do a great job in giving us clean electricity. However not all greenhouse gases come from making electricity. Clean electricity solves only part of the greenhouse gas problem.

3 The chart shows where all our energy came from in 2016-17. The renewables we have now are very good at making clean electricity, and are gradually replacing old high emission generators, usually coal, thus cleaning up the electricity sector. Unfortunately, a large percentage of harmful emissions – over 60% as shown on this chart - still comes from sectors that use liquid or gas for fuel. 60 % is a lot of greenhouse gas.

4 You will be familiar with all of these. They all use oil or gas. They can be summed up as 'things that move'. These things that move present a real problem.

The aviation industry, the shipping industry, the trucking industry, the farming industry, at least part of the bus and rail network. It also includes a greater percentage of private cars and boats.

I'm sure everyone understands that grid power and batteries do not provide a feasible clean power solution for all these sectors.

There is one other real biggie for Australia. It has been a major stumbling block in the path to clean energy. EXPORT. How do we replace our current energy export industries that provide us with a lot of cash and more than a few jobs? Instead of coal and LNG, how can we export our abundant sunshine and wind?

5 More than half of Australia is in effect a giant solar collector. According to Professor Moalem in Forbes magazine, a small percentage of it, an area as small as 335 km x 335 km could provide the whole world with energy, yet currently we have no affordable way of capturing and exporting all that energy.

There are many countries wanting to import clean energy so they can move to a carbon-free economy.

Australia's next big export industry could be our sunshine and wind, **if** we develop the technology that enables us to convert that energy into a storable and transportable form. Australia is very good at producing affordable renewable electricity. Now we have to concentrate on ways to store and transport it.

6 Hydrogen

Lately we've been hearing about Gladstone being a possible hub for Hydrogen.

There is a great deal of interest world-wide in Hydrogen.

7 We have all seen pictures of hydrogen powered cars brought over here for testing by Hyundai - the Tucson, and Toyota - the Mirai.

By the way these are all electric vehicles, like the Tesla, except that instead of batteries they use Hydrogen Fuel Cells to provide the electricity.

8 This is the Hydrogen Fuel Cell (HFC) sports car developed by Grove, a Chinese company. After a visit to Japan in May 2018, where he saw the Toyota Mirai, Chinese Premier Li assembled a team to develop HFC vehicle technology. The central authorities' development plan for hydrogen fuel technology set targets of getting 5,000 hydrogen energy vehicles on the road by 2020, 50,000 by 2025, and 1 million by 2030. 1 million is almost the number of new vehicles sold in Australia each year.

9 In the USA, Toyota has developed a hydrogen fuel cell delivery vehicle with a 670 hp fuel cell and a 500 km range. Nikola Motors in Salt Lake City has a 1000 hp hydrogen fuel cell semitrailer with a range of 1,900 km. That's Gladstone to Melbourne. Nikola is busy setting up a network of hydrogen service stations on popular truck routes in the USA. They claim to have 11,000 pre-orders for their HFC semis.

10 In case you've been fretting about it, here's our Hydrogen powered tradies' ute, the Chevrolet Silverado ZH2. Currently it is being evaluated by the US military for its use, and is on its way to the open market.

11 In China Great Wall are developing their own Hydrogen fuel cell ute, also coming soon to a showroom near you.

12 A Hydrogen train service began in Northern Germany in September 2018. The 2 trains run back and forth on a 100km line. Each train has a range of about 1000 kms on one tank of Hydrogen (about the same range as the diesel engine it replaced). They can reach speeds of 140 kph, and are cheaper to maintain. The only emission is water. Lower Saxony has ordered 14 more of these trains by 2021.

13 London has already started operating hydrogen buses …..

14 … as have numerous other places such as Cologne in Germany, Antwerp in Belgium, Milan in Italy, Aberdeen in Scotland, and many other places such as China,

India, Brazil, Columbia, Norway, and Canada, to name just a few. All these use hydrogen fuel cells to provide their electricity.

15 There are now hydrogen fuel cell power stations up and running. This one is near Seoul in South Korea, and there is another at Fusina near Venice in Italy. Last year Japan began producing hydrogen fuelled power at a test site at Kobe. In Australia, the $117 million hydrogen plant in Port Lincoln SA is due for completion in 2020. Its gas turbines will generate electricity using hydrogen alone.

16 Hydrogen fuel cells are nothing new. The idea was conceived in 1801. In more modern times hydrogen fuel cells provided the Apollo moon ships, including Apollo 11, with electricity and water.

17 Some stealth submarines weighing thousands of tons are propelled with HFCs and can remain submerged for weeks.

18 How does a Hydrogen Fuel Cell work?

Put very simply, this is the nub of it. Here's our hydrogen atom, with one proton – positive, and one electron – negative. The heart of the cell is the proton exchange membrane. It allows protons to pass through, while electrons are blocked. So, when it hits the platinum catalyst the hydrogen splits into protons and electrons. The protons go directly through to the cathode side, while the electrons are forced to travel through an external circuit. Along the way they perform useful work, like lighting a bulb or driving a submarine, before combining with the protons and oxygen from the air on the other side to produce water. Note that there are no moving parts.

World-wide there is a huge amount of scientific research and development involving hydrogen technology.

19 The Australian Renewable Energy Agency ARENA, reported in July 2018 that 'Since the meltdown at the Fukushima nuclear plant in 2011, the Japanese Government has accelerated its search for new energy sources, spending more than $16 billion on hydrogen research and development.'

20 China is spending $120 billion – that's 120 thousand million per year on renewables, and is very interested in using hydrogen for fuel, and as a clean energy storage medium. This year Japan and China have hosted conferences and trade fairs to showcase hydrogen technology. So have other countries such as the UK, in Warwick and Birmingham for example, and even in the Czech Republic, and in Germany, the USA and many others too numerous to mention.

We're emphasising this because we and perhaps others here, were not aware of how far the technology has come and how little awareness of this there is here in Gladstone and perhaps in the rest of Australia.

More information about hydrogen vehicles was published in *New Scientist* of 8 Sept 2018 in their "Insight" column on Hydrogen Cars. To quote:

21 'Hydrogen fuel cells are already finding applications in heavy use vehicles. Japan will showcase 100 hydrogen buses at the 2020 Tokyo Olympics (that's next year). South Korea plans to introduce 1000 hydrogen buses by 2022. Still from New Scientist:

'Japan and South Korea are leading this [hydrogen] push because they want to embrace a zero emissions policy, but their combination of small land mass and large population means they don't have enough solar, wind, or other renewable [generation capability].

New Scientist goes on to say

'They can't import the renewable energy itself, but they can import hydrogen made from renewable energy in other countries. Australia for example could use its abundant solar energy to split water and export hydrogen to these countries. "You can see hydrogen basically as a carrier for renewable energy" said Dr Michael Dolan' [from the CSIRO]

22 Here in Australia on 6 Sept 2018, it was announced that ARENA, which is a federal government body, was giving $22 million in research grants to various universities, and the CSIRO, for 16 research projects into the manufacture, storage, and use of hydrogen as a fuel

These are just a few examples of the extensive global interest in Hydrogen.

Why is everyone so interested in Hydrogen

23 Hydrogen is often described as the **ultimate clean fuel** because

A) it can be manufactured completely renewably and cleanly.

B) The only emission arising from the use of hydrogen is water.

C) It can replace all the damaging fossil fuels: It can replace coal in power stations AND can replace petrol, diesel and gas as a fuel in transport.

24 This diagram from the CSIRO's National Hydrogen Roadmap, 23 August 2018, shows the many uses for hydrogen in our energy economy. It can be used for electricity, heating, transport, export, and as an input product into many manufactured goods.

So, we can see that hydrogen has huge potential.

Unfortunately there's no such thing as a free lunch, especially at Repower Gladstone meetings. Hydrogen does have a few problems.

25 The major issue with hydrogen in large quantities is its storage and transportation.

- It has very small molecules which can leak out of hoses and containers
- It makes some metals brittle and thus requires periodic replacement of metallic tubing, valves and tanks

- It has a wide range, when mixed with air, over which it can ignite or explode, so it must be handled with care. Contamination of liquid hydrogen with even tiny amounts of liquid air can make it unstable and dangerous.

So how are we to safely produce, store and transport large volumes of hydrogen? Is there a special metal, or a chemical that can be used to hold hydrogen?

26 Introducing Ammonia

Chemical engineers have long known that Ammonia (NH_3) contains a high density of Hydrogen. In fact there's more hydrogen in liquid ammonia than in liquid hydrogen!! (by volume, that is). This sounds counter-intuitive, but it is due to the way the atoms are packed in the molecules.

27 Remember your high school chemistry? Ammonia has 3 atoms of hydrogen in every molecule, while hydrogen itself has only 2. In equal volumes of liquid ammonia and hydrogen, ammonia contains 50% more hydrogen.

Ammonia has other features that make it a winner for transport and storage.

28 It requires little cooling to become a liquid at -33^{o}C (sounds like Canberra on a bad day), and it can be stored with or without continuous cooling. Compare this with LNG that requires -160^{o}C to liquify, and then needs continuous cooling to remain liquid. Hydrogen is even worse, requiring -253^{o}C in a complex procedure to liquify, and then it requires constant refrigeration.

So, ammonia is comparatively easy and economical to liquify, store, and transport. This is happening.

29 It is this ability to transport hydrogen economically in the form of liquid ammonia, by road, rail, sea, or pipeline, that has long held the interest of scientists.

30 This map shows ammonia pipelines currently existing in the USA, running over 3000 miles – that's 5000 km, through Indiana, Oklahoma, Texas, Minnesota, among other states. So safe transport of ammonia is well established.

One detail that has held back transporting hydrogen using ammonia as a carrier, has been how to get the hydrogen out when we want it. Separating hydrogen from ammonia economically has been a difficult problem until -

31 a recent invention by Australia's CSIRO scientists in Brisbane.

In 2017 they announced that they had developed a metal membrane made of vanadium, so fine that -

32 Once ammonia disassociates into nitrogen and hydrogen, at about 430^{o}C, the membrane allows the tiny hydrogen molecules through but not the larger Nitrogen ones. The nitrogen can be released or retained as desired, and the extremely pure hydrogen used as a fuel. This separation could be done at the point of hydrogen sale, or as technology improves, on board the vehicle using the hydrogen. In 2019 we learned that they have taken the process to Japan for further testing.

33 On the ABC news, on 9 August 2018, they had this to say:

Some advantages of ammonia

34 It can be stored indefinitely without deterioration
It is reasonably energy dense
It is easy to store, it does not corrode steel containers or easily leak, like hydrogen does
At 150 psi it reaches equilibrium at normal temperature so it can be stored without refrigeration.
The only fuel used in making it is sunlight, so it can be manufactured forever – well until the sun burns out. Water and Nitrogen return to their original state when the ammonia is used.

35 More ammonia facts:

With some 200 million tons being manufactured each year ammonia is the second most manufactured chemical in the world, after sulphuric acid. It does need careful handling (as does petrol and gas). World-wide its handling, storage and transportation are well understood. Indeed, Orica here in Gladstone handles over half a million tons per year, apparently with little problem.

36 Anhydrous ammonia (meaning without water) has been used by farmers for over 100 years, as a fertilizer.

37 Internal combustion engines such as we use in our cars today can, with modification, use ammonia directly as a fuel, and it *was* used in Belgium to power buses in WW2, due to wartime fuel shortages.

38 It was used with liquid oxygen to power the X15, the fastest piloted aircraft ever built, at 7,274 kph. At that speed from here to Perth would take 30 minutes !!! The highest and longest flight in an X15 was piloted by none other than Neil Armstrong.

The most efficient way of using hydrogen to power a vehicle is with a fuel cell. A hydrogen fuel cell has more than double the efficiency of an internal combustion engine. However, with little modification current internal combustion engines can use ammonia as a fuel without separating it into its components. This would allow today's vehicles to continue in use until new fuel cell vehicles – hydrogen or ammonia - become readily available.

39 So the good news is we won't have to dump the old Fords and Commodores just yet.

40 How do we make ammonia

We currently make ammonia by forcing together nitrogen and hydrogen at a **very** high temperature and pressure. The process is known as the Haber Bosch method, and this technology is now over 100 years old. Here's a nice picture of the Orica ammonia plant in Newcastle.

The current process being used is not particularly clean or efficient. Processes which are completely clean and much more energy efficient, such as making ammonia directly from sunlight, water and nitrogen, are being developed now. For example

41 In the New Scientist of 19 May 2018, (and in other science publications) they announced that Xiaofeng Feng and his colleagues at the University of Central Florida in Orlando have created a **single step** process that uses water, nitrogen from the air, electricity, and a palladium catalyst to turn the ingredients into ammonia. This process works at room temperature and normal pressure. Early tests show it uses much less power than the Haber Bosch method, and is clean. This is an exciting new advance, and if commercialized will allow totally green ammonia to be made just about anywhere in Australia at a competitive price. This could be another game-changer.

Others are achieving similar results with Lithium Hydroxide as a catalyst.

42 Indicative of how fast this field is evolving we have learned recently that Professor Douglas MacFarlane from Melbourne's Monash University has won the 2018 Victoria Prize for Innovation and Science. The prize was for his teams very promising work using **ionic liquids** to make ammonia, also in a highly desirable one step process, without high heat and pressure. On the Science Show on Radio National on 13 April 2019, Professor MacFarlane talked about his work in this field, and about the export potential of ammonia and hydrogen.

43 Wouldn't it be a feather in Australia's cap if after 100 years of manufacturing ammonia, it was Australian innovation that made it a viable medium for storing and transporting completely clean affordable energy for the world? Our scientists would be responsible for solving both ends of the ammonia problem – how to make it and how to break it, cleanly and affordably.

So how could it work in practice in Gladstone or the rest of Australia?

Here is one possibility, by no means the only one.

44 Clean energy (e.g. wind, solar, hydro, geothermal, thermal solar) would supply electricity to the grid, which distributes that power to various consumers, as you can see here, to Industry, to commercial premises, and to households. This is a 2-way street as these premises would all be equipped with solar panels and can feed their excess power back to the grid.

By design the various clean power generators would produce **much** more power than required for immediate consumption. That surplus power is sent to an ammonia plant which converts the power to gaseous ammonia. It only needs clean energy, water, and nitrogen. This field is rapidly evolving and would involve scientists selecting the most cost-effective and cleanest way of making ammonia. Part of this new membrane technology is already used on Curtis island to extract Nitrogen from the air.

45 From the ammonia plant the ammonia would then be piped to a liquification plant, where it can be liquefied at an easy -33^{o}C, reducing its volume by 850 times. From the liquification plant the ammonia would be piped to designated storage tanks,

eg Curtis Is. Major coal powered stations could be converted to use ammonia or hydrogen, and fired up to send power to the grid only when it's needed, for example at peak load. All the electrical distribution system could then stay in place. The only emissions from this process are water and nitrogen.

46 From the storage tanks the ammonia would be sent by truck, rail or pipeline for use in gas-fired power stations in small towns where it is not economical to connect to the grid. It can be supplied to Service Stations for use in hydrogen vehicles, and to some sectors of industry.

Ships previously built to carry LNG could easily be converted to transport surplus ammonia to overseas countries not as blessed as Australia with sun and wind. This would earn Australia good export dollars, and the CSIRO would earn money from licensing its technology. We would be exporting not only clean energy, but also Australian technology.

This isn't all going to happen overnight. It's something to work towards. When the USA's main transport system changed from steam trains using coal to cars and trucks using petroleum, it took more than 40 years and $500 billion (in today's money) to build the interstate road system. It created hundreds of thousands of jobs. If we move towards a hydrogen/ammonia economy, it too would create many **many** thousands of jobs to replace those lost in the fossil fuel industry. We could be world leaders in clean energy supply and technology. Australia more than most countries has abundant sunshine and wind. In producing ammonia we would have an endless supply of a much sought-after product. With ammonia as an energy carrier we would be selling our wind and sunshine to the world.

A clean hydrogen/ammonia economy could be introduced **incrementally**. I.e. Solar farms, ammonia plants and ammonia storage tanks could be built in affordable sized units and used immediately. Compare that with a pumped hydro storage system, which has merit as clean energy storage, but it would cost billions of dollars and take years before it stored 1 usable watt of electricity. Also its surplus power can't be exported. Stored ammonia gives the option of using it in Australia or exporting it.

47 There is no emission-free naturally occurring product to replace liquid and gas fossil fuels, so we must make our own.

Hydrogen and ammonia fit the bill.

We have the technology. Now we need the political will. Some leaders may choose to ignore the mounting evidence that burning fossil fuels is causing an environmental catastrophe. Let's hope that they won't ignore the huge economic opportunity presented by selling our green energy.

48 Australia should move quickly to ensure it doesn't miss the boat as a supplier to this rapidly developing lucrative hydrogen market.

Thank you. Any questions?