Hydrogen

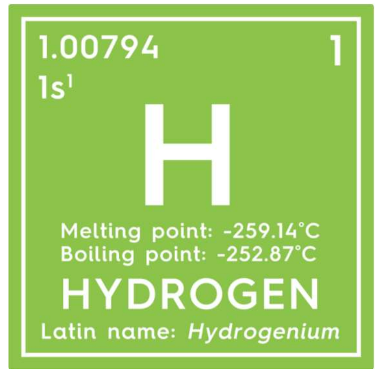
A Modern Energy Source?

Woodside Australian Science Project

An initiative supported by

What is hydrogen?

- Most abundant element in the universe
- Very effective energy carrier



Hydrogen is everywhere, but rarely exists as a gas in Earth's atmosphere because of its extremely low density.
Hydrogen contains much more energy per kg than petrol (140 MJ/kg vs 44 MJ/kg).
The huge advantage of using hydrogen for power is that it combines with oxygen, via combustion, or in fuel cells, with water as the only emission product.

History of hydrogen

- 1776 – formally identified
- 1839 – first hydrogen-powered fuel cell
- 1920s to 1930s – used in airships crossing the Atlantic
- 1960+ – used for spacecraft

Hydrogen has been used in commercial quantities for more than 100 years.
Although we think of hydrogen fuel cells as a modern innovation, the first one was created by William Robert Grove in 1839.
Its first transport use was in airships (blimps) that crossed the Atlantic.
From the 1960s, the powerful combustion of hydrogen and oxygen was used to power space craft.

How do we use hydrogen today?

Hydrogen is produced from fossil fuels

- 50% to make ammonia
- 40% to ‘crack’ petroleum
- Remainder: glass production, electronics manufacture, etc.

Chemical plant that produces ammonia and fertilisers

The vast majority of hydrogen used today is produced from fossil fuels using heat and chemical reactions.

Hydrogen is mainly used to make ammonia in the Haber process. This process consumes 3-5% of the world’s natural gas production. The ammonia is used directly as a fertiliser, or as ammonium nitrate or urea.

Hydrogenation of petroleum (hydrocracking) is used to break long carbon chains into lighter products that are used as fuel.

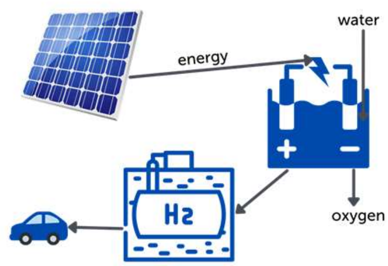
References:

Dawood F, Anda M, Shafiullah GM (2020). Hydrogen production for energy: An overview. *International Journal of Hydrogen Energy* **45**(7): 3847-3869. https://doi.org/10.1016/j.ijhydene.2019.12.059

C Rivkin, R Burgess, W Buttner (2015). Hydrogen technologies safety guide. *National Renewable Energy Laboratory Technical Report NREL/TP-5400-60948*. https://www.nrel.gov/docs/fy15osti/60948.pdf

Hydrogen fuels

- Another way to produce hydrogen is by electrolysis of water
- The hydrogen is then stored until needed
- Hydrogen fuel cells can power transport and utilities
- Combustion emission is water



What difficulties must be overcome?

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- Safety
- Production
- Storage
- Setting standards

Although we have a long history of hydrogen production and use, there are hurdles to overcome in implementing hydrogen power on a large scale. These include safety, production, storage and setting standards.

Safety

- Hydrogen and oxygen combine explosively
- Makes metal brittle
- Safety procedures needed if the general public is going to handle hydrogen (e.g. refuelling cars)

Hindenburg disaster. May 6 1937 in Lakehurst, New Jersey

Hydrogen and oxygen combine explosively, which is why hydrogen is used as rocket fuel. Students use this to test for hydrogen on a small scale in the "pop test". Hydrogen combustion releases large amounts of energy, but presents significant safety challenges.

In 1937 the hydrogen-filled German airship, Hindenburg, caught fire and was destroyed while attempting to dock in New Jersey. The accident left 36 people dead and many severely injured. The disaster abruptly ended the airship era.

Hydrogen can make metal brittle. This presents a challenge for storage, transport and use, which traditionally rely on metal pipes.

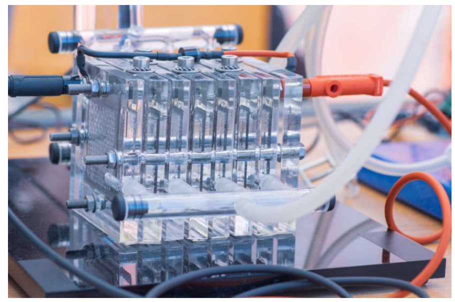
Hydrogen is used on an industrial scale by skilled workers. If the general public is going to use hydrogen to refuel cars, safe delivery systems are vital.

Reference:

C Rivkin, R Burgess, W Buttner (2015). Hydrogen technologies safety guide. National Renewable Energy Laboratory Technical Report NREL/TP-5400-60948.
https://www.nrel.gov/docs/fy15osti/60948.pdf

Safety solution: fuel cells

- Produce electricity by combining oxygen and hydrogen without combustion



Hydrogen fuel cells allow hydrogen and oxygen to combine in a controlled manner, without the combustion reaction. The energy stored in hydrogen is released as electricity. Hydrogen fuel cells can be used to power electric vehicles and as backup generators. Single fuel cells are combined into stacks, much like single cells are combined into batteries.

Providing hydrogen to fuel cells still has safety challenges. Some of these are addressed in the production and storage slides.

Recommended viewing:
The truth about hydrogen fuel cell – a future beyond cars? From Undecided with Matt Ferrell (9:33) https://youtu.be/DTPt32lZY30 He discusses how fuel cells work and their efficiency. Spoiler alert – he thinks fuel cells are not terribly efficient, but still have their uses. Not reasonable for passenger vehicles, but many opportunities for stationary power. (Other presenters argue more strongly for hydrogen vehicles.)

Production

- More than 90% is from fossil fuels
- Electrolysis of water is more expensive and less efficient
- Bioproduction is currently being researched

Currently, 96% of hydrogen production is from fossil fuels. This is sometimes called grey hydrogen.

Green hydrogen is produced from the electrolysis of water, powered by renewable energy. At present, it is more expensive and less efficient to produce hydrogen from the electrolysis of water than from fossil fuels. As renewable energy infrastructure grows and hydrogen infrastructure is developed, the cost will decrease.

There are a variety of biological options for production. These include obtaining hydrogen from biogas (methane) rather than natural gas (fossil fuel methane); the use of photosynthetic algae; or dark fermentation. Dark fermentation, by bacteria, produces hydrogen through the breakdown of organic waste.

Reference:
CSIRO. Dark fermentation. From: https://www.csiro.au/en/work-with-us/ip-commercialisation/hydrogen-technology-marketplace/Dark-fermentation
Tatiane da Silva Veras, Thiago Simonato Mozer, Danielle da Costa Rubim Messeder dos Santos, Aldara da Silva César (2017). Hydrogen: Trends, production and characterization of the main process worldwide, *International Journal of Hydrogen Energy*, **42**(4): 2018-2033
https://doi.org/10.1016/j.ijhydene.2016.08.219

Storage

- Low density (11 m^3 = 1 kg)
- Storage options:
  - Pure gas or liquid
  - Chemically bonded

This liquid hydrogen storage tank at Kennedy Space Center was used to fuel the space shuttle. (TomFawls 2013, Creative Commons 3.0)

Hydrogen storage is challenging because of its low density (11 m^3 = 1 kg). Energy input is needed to increase density. Different storage solutions suit different applications.
Underground storage in salt cavities is the lowest cost option, with minimal contamination. Local geology limits this application.
Liquefication of hydrogen is energy intensive and it is expensive to build plants. Tanks to store the hydrogen must be well insulated with double walls and insulation between them. They are spherical for the most favourable surface-area-to-volume ratio. The largest tanks (holding 200+ tonnes) are at space facilities such as Cape Canaveral.
Chemical bonding offers great advantages for stable transport of hydrogen but requires energy to release the hydrogen. Metal hydrides are easy to store and control as solids. Chemical hydrides are liquids such as methanol and ammonia. These chemicals are commonly synthesised for industry. The infrastructure for transport and handling are in place. It is predicted that they may outperform hydrogen liquefaction in the future.

Reference:
J Andersson, S Grönkvist (2019). Large-scale storage of hydrogen. *International Journal of Hydrogen Energy* **44**: 11901-11919.

Setting standards

- International standards being developed for:
  - Use
  - Production
  - Storage
  - Transport
  - Refuelling
  - Measurement
  - Purity

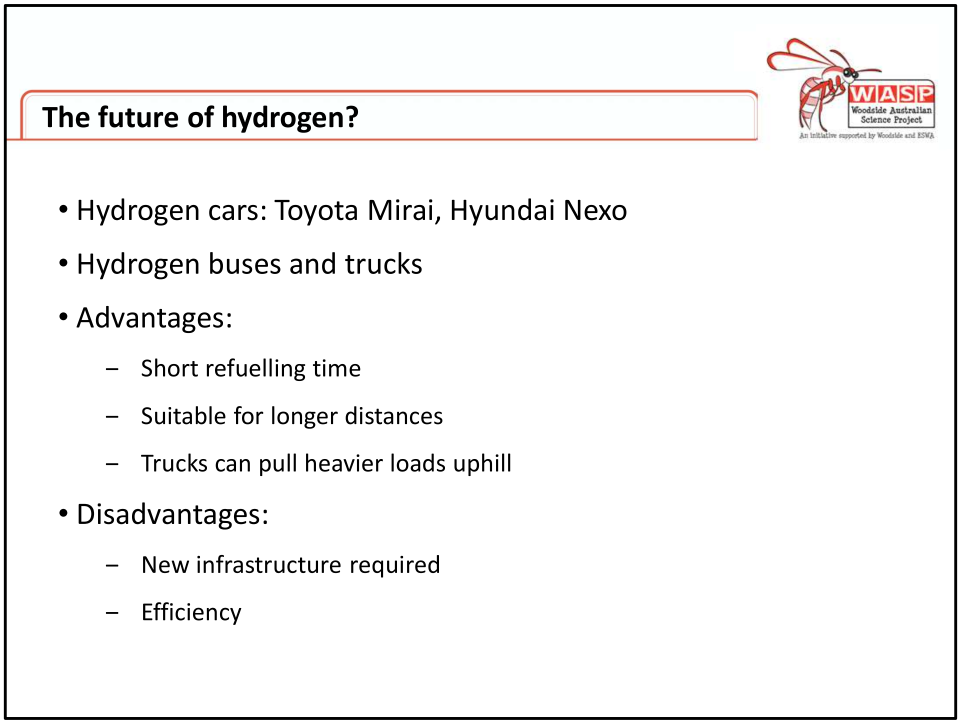
We don’t notice the many international standards that help to make life easier.

The standards around petrol are a good example. Although cars are made in many different countries, all use the same standardised fuel pumps and can use the fuel produced by different companies, because this is also standardised.

One problem with electric cars is different charging connectors.

Hydrogen fuel standards are needed so that we can refuel with hydrogen as easily as we do with petrol.

Reference:
Dawood F, Anda M, Shafiullah GM (2020). Hydrogen production for energy: An overview. *International Journal of Hydrogen Energy* **45**(7): 3847-3869. https://doi.org/10.1016/j.ijhydene.2019.12.059
Lilly C (2020). EV connector types. From: https://www.zap-map.com/charge-points/connectors-speeds/



Hydrogen fuelled cars from Toyota and Hyundai are commercially available.

Advantages for hydrogen are quicker refuelling time and lighter mass.

Hydrogen infrastructure is slowly being rolled out. However, many commentators believe that battery-powered electric car will be the major choice, because they are cheaper to run and more efficient. Battery-powered cars are 70 – 80% efficient, whereas hydrogen powered ones are 35 – 40%. However, hydrogen fuelled buses and trucks have many advantages, including a shorter refuelling time and the ability to travel longer distances before refuelling.

References:

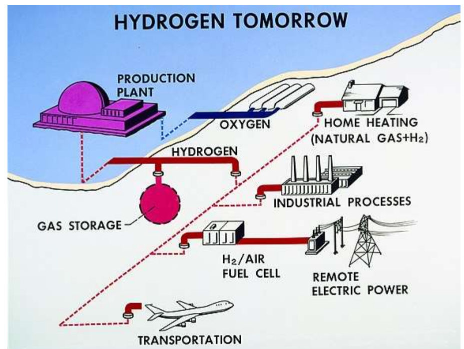
Baxter T (2020). Hydrogen cars won't overtake electric vehicles because they're hampered by the laws of science. From: https://theconversation.com/hydrogen-cars-wont-overtake-electric-vehicles-because-theyre-hampered-by-the-laws-of-science-139899

Ferrell M (2020). *The truth about hydrogen fuel cell – a future beyond cars?* From Undecided with Matt Ferrell (9:33) https://youtu.be/DTPt32lZY30

Sunday Times Driving (2021). James May has written the best battery vs hydrogen electric car summary we've read. From: https://www.driving.co.uk/news/technology/james-may-written-hydrogen-manifesto-instead-reviewing-toyota-mirai/

The future of hydrogen?

- Home heating
- Industry
- Power generation
- Transportation



Possible uses of hydrogen:

- to replace or augment natural gas, using existing distribution networks. Hydrogen boilers or fuel cells could be used for heating and cooking instead of natural gas
- the many industrial processes that rely on hydrogen (like steel production)
- hydrogen could be used as a store of renewable energy
- heavy vehicles, like buses or trucks (or even planes), may suit hydrogen fuel cells

Hydrogen is expected to be one of the important fuels of the future, but its roles are still being explored.

References:
Ferrell M (2020). *The truth about hydrogen fuel cell – a future beyond cars?* From Undecided with Matt Ferrell (9:33) https://youtu.be/DTPt32lZY30
IEA (2019). The future of hydrogen: Seizing today's opportunities. From: https://www.iea.org/reports/the-future-of-hydrogen
Purtill J (2021). What is green hydrogen, how is it made and will it be the fuel of the future? From: https://www.abc.net.au/news/science/2021-01-23/green-hydrogen-renewable-energy-climate-emissions-explainer/13081872

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