NPL
National Physical Laboratory

Hydrogen fuel cells and measurement challenges

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Future Propulsion Conference

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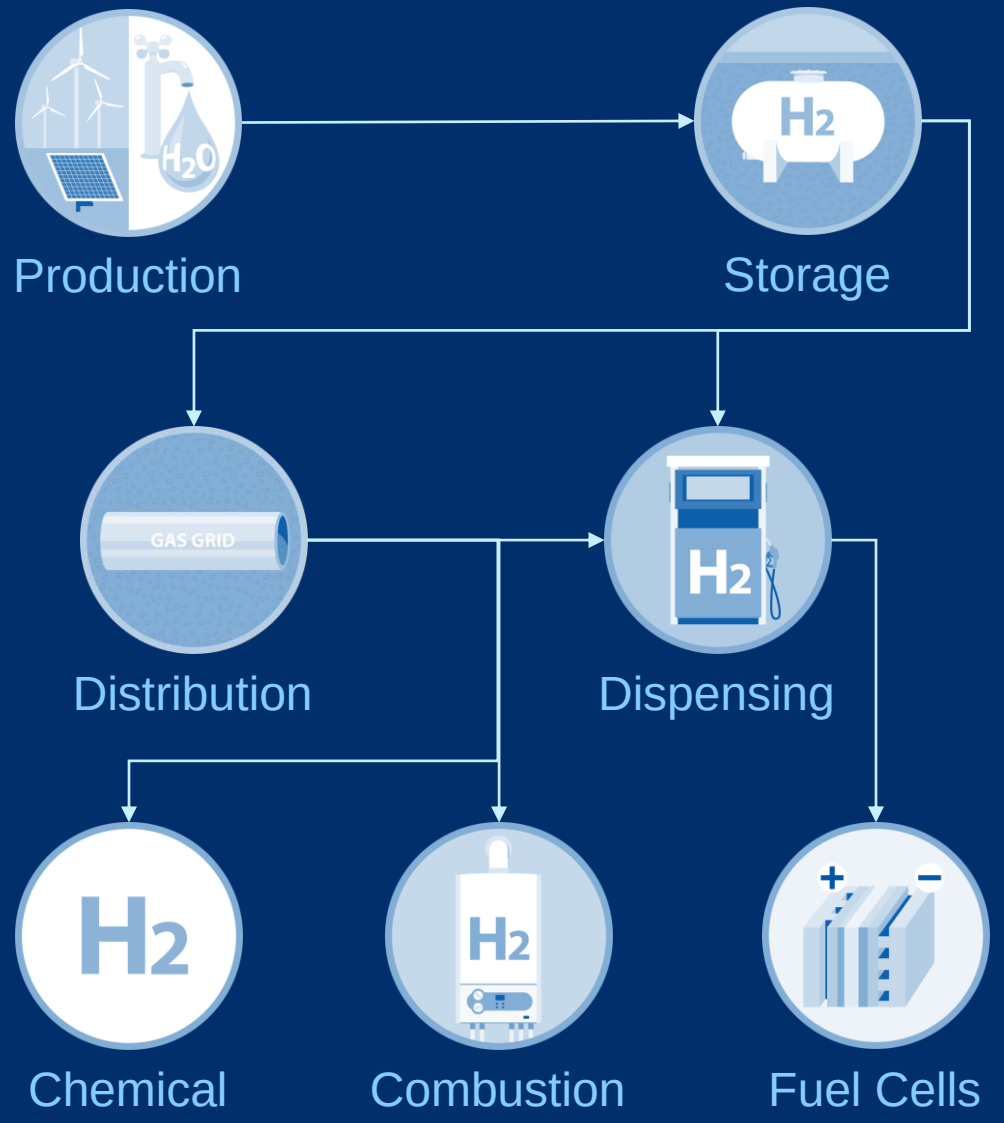
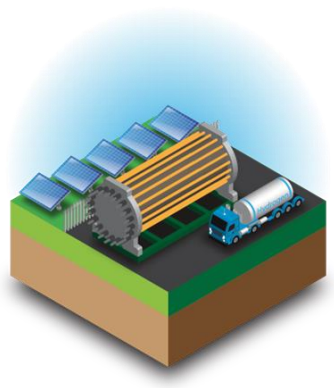
Hydrogen At NPL

- A public sector research establishment owned by the UK Government
- Impartial and independent
- Founded in 1900 with a mission to *"bring scientific knowledge to bear practically upon our everyday industrial and commercial life"*
- Over 800 scientists in over 440 laboratories
- The UK's National Metrology Institute responsible for maintaining, and developing new, measurement methods and standards

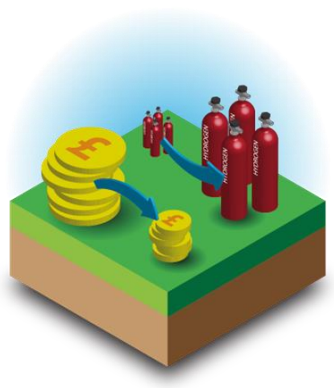


Fuel Cell Vehicles vs Hydrogen

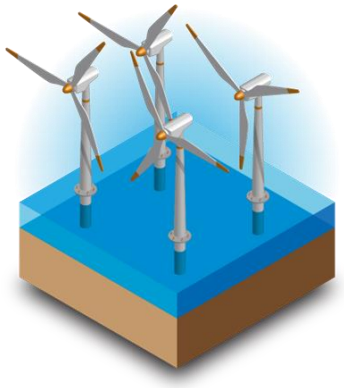
- Broadly, fuel cell vehicles work
  - Performance
  - Durability
  - Saleability
  - Capital cost
- Supply of hydrogen an issue
  - Big contributor to TCO
  - Availability limitation to scale up



Scalability
Scalable to 1 TW installed capacity by 2050



Cost
Cost of hydrogen competitive with alternative energy vectors



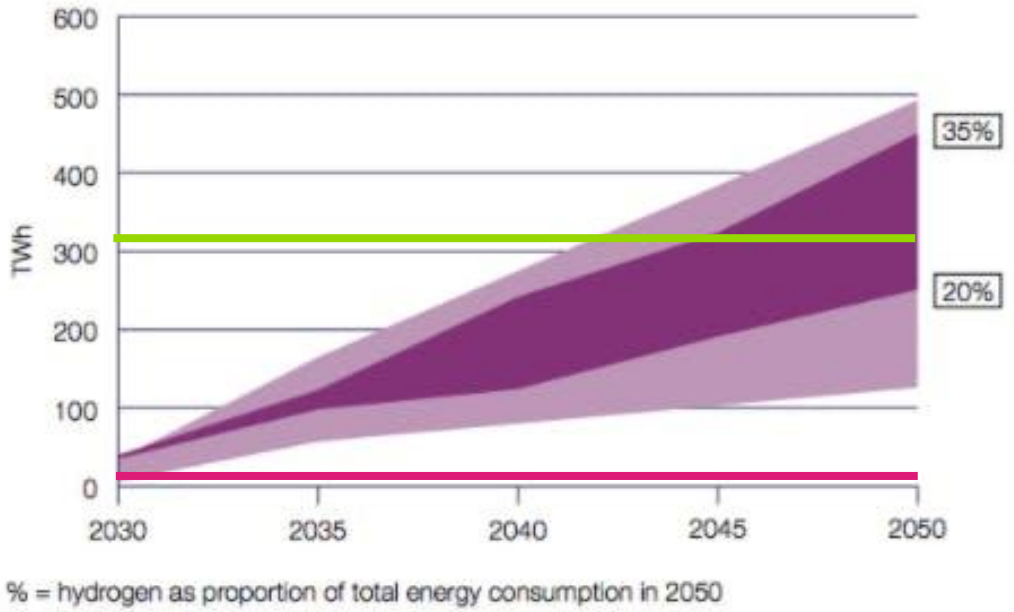
Cleanliness
Meeting emissions targets to be truly low carbon 20 g_{CO2} kWh_{LVH}^{-1}

Future of Hydrogen

- Plans for hydrogen to be everywhere

- Will it all be suitable for hydrogen vehicles?
  - ✓ Availability
  - ✓ Lifecyle emissions
  - ✓ Cost
  - ✓ Pressure & temperature
  - ? Quality

2022 UK Electricity Grid ~ 300 kWh
2022 Global Battery Production Capacity ~ 2.5 TWh

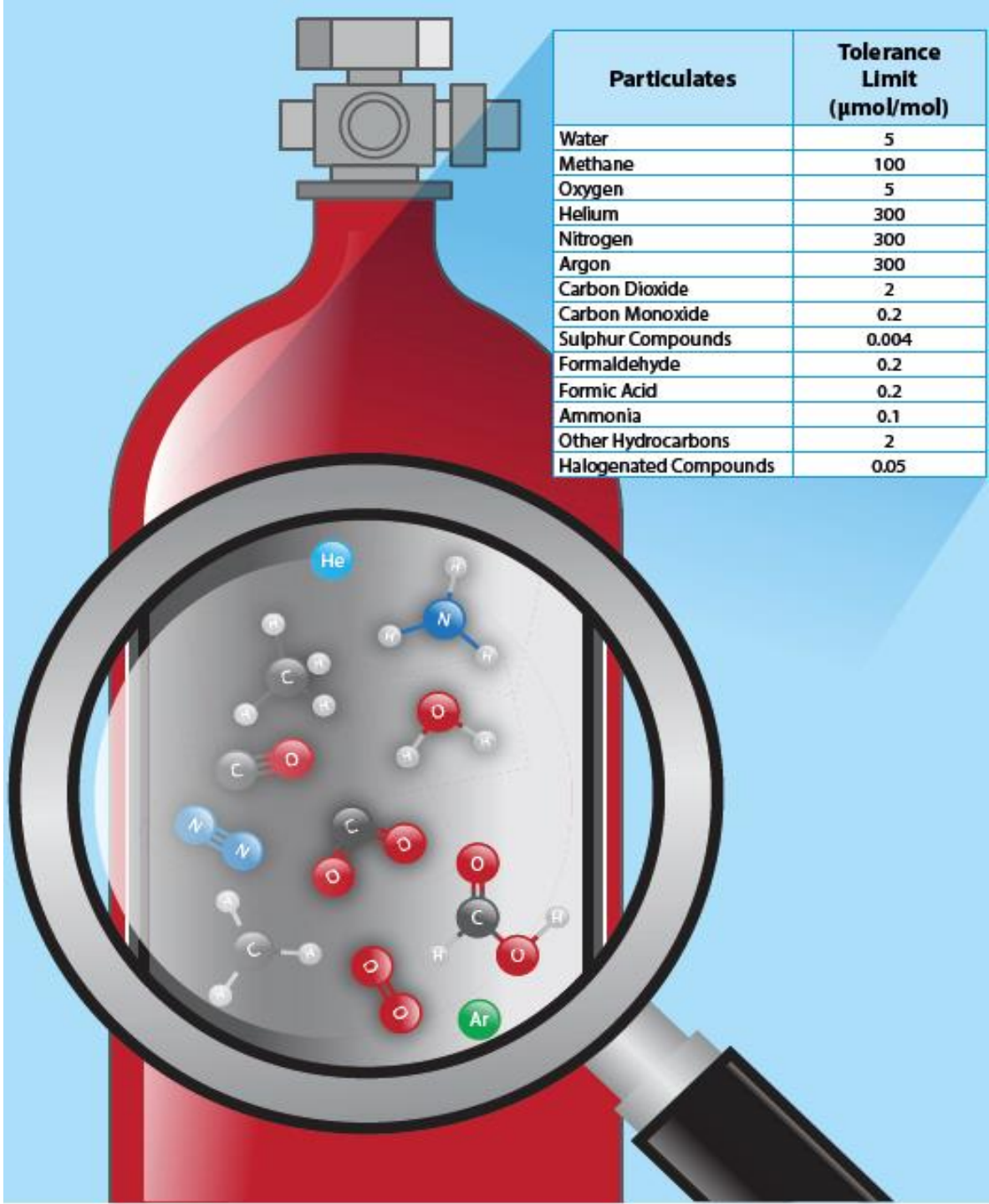


% = hydrogen as proportion of total energy consumption in 2050

Hydrogen Quality

- PEMFC are damaged by impurities
  - Performance
  - Durability

- Standard for PEMFC hydrogen
  - ISO 14687 defines permissible hydrogen
  - ‘Only’ 99.97 % purity
  - Tolerance for sulphur 4 µmol mol^{-1}



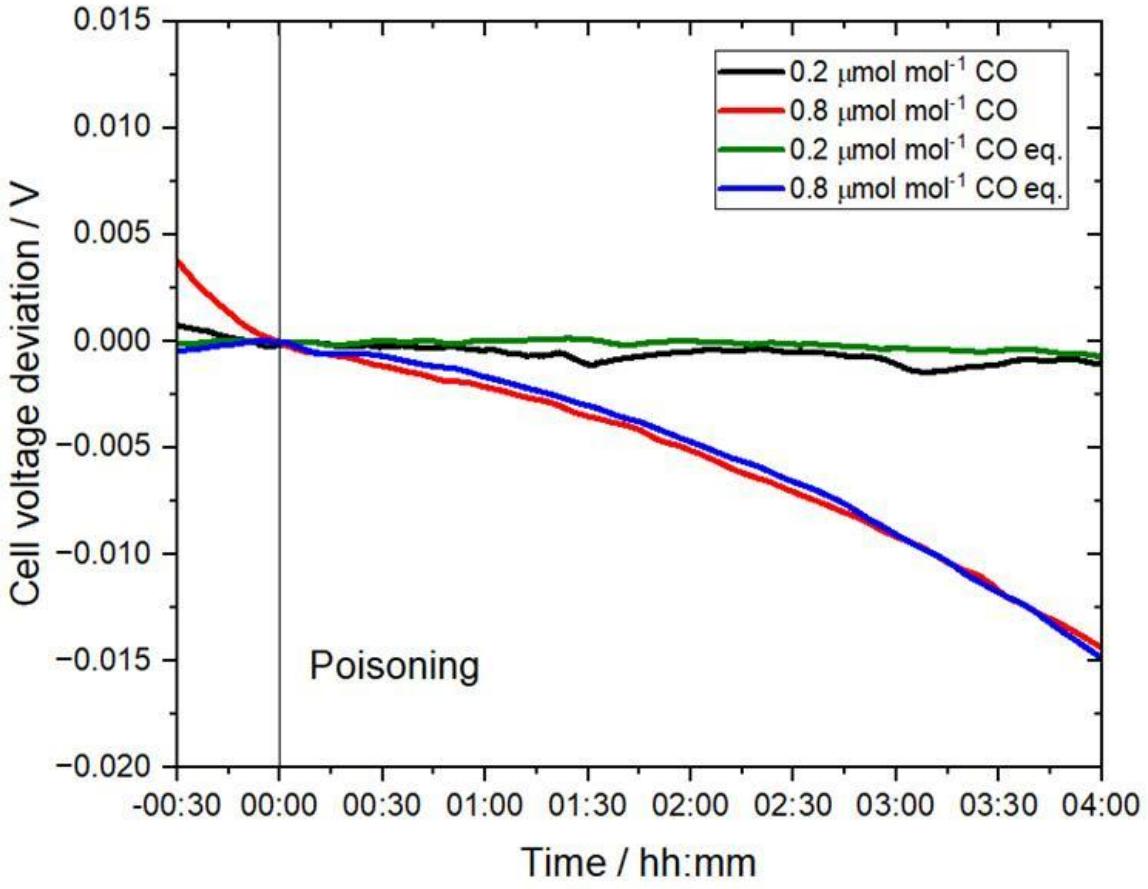
Particulates	Tolerance Limit (µmol/mol)
Water	5
Methane	100
Oxygen	5
Helium	300
Nitrogen	300
Argon	300
Carbon Dioxide	2
Carbon Monoxide	0.2
Sulphur Compounds	0.004
Formaldehyde	0.2
Formic Acid	0.2
Ammonia	0.1
Other Hydrocarbons	2
Halogenated Compounds	0.05

Impact on PEMFC Performance

- Developed multi-component mixtures to simulate ‘worst case’ under the standard

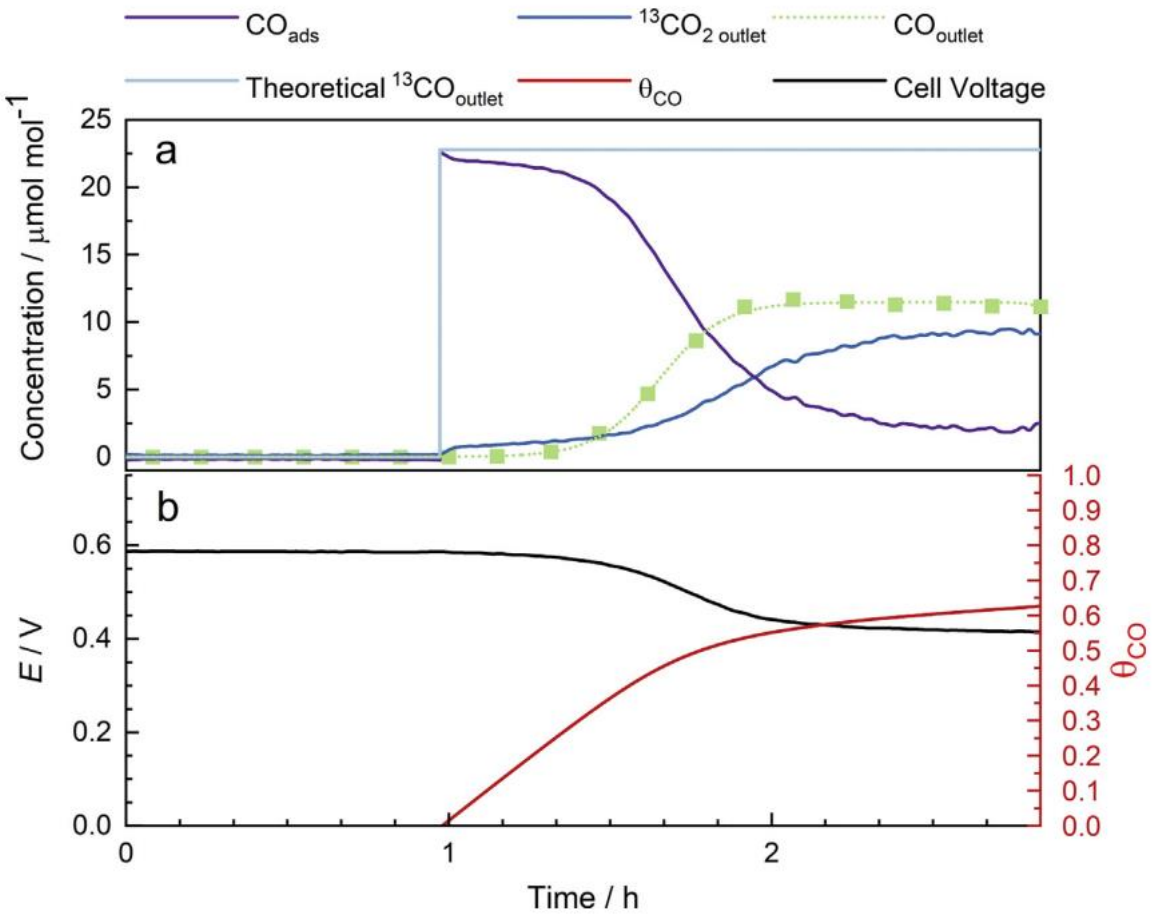
Components	Chemical formula	Standard Concentration / µmol mol^{-1}
Methane	CH_4	10000
Toluene	C_7H_8	31
Carbon monoxide (with ^{13}C)	^{13}CO	20
Carbon monoxide (with ^{12}C)	^{12}CO	0.20
Ammonia	NH_3	9.8
Dichloromethane	CH_2Cl_2	2.6
Total Sulphur	H_2S	0.34

- Experiments carried out 1 kW short stack at conditions representative of automotive PEMFC



Provisional, unpublished results

Diagnostic Experiments

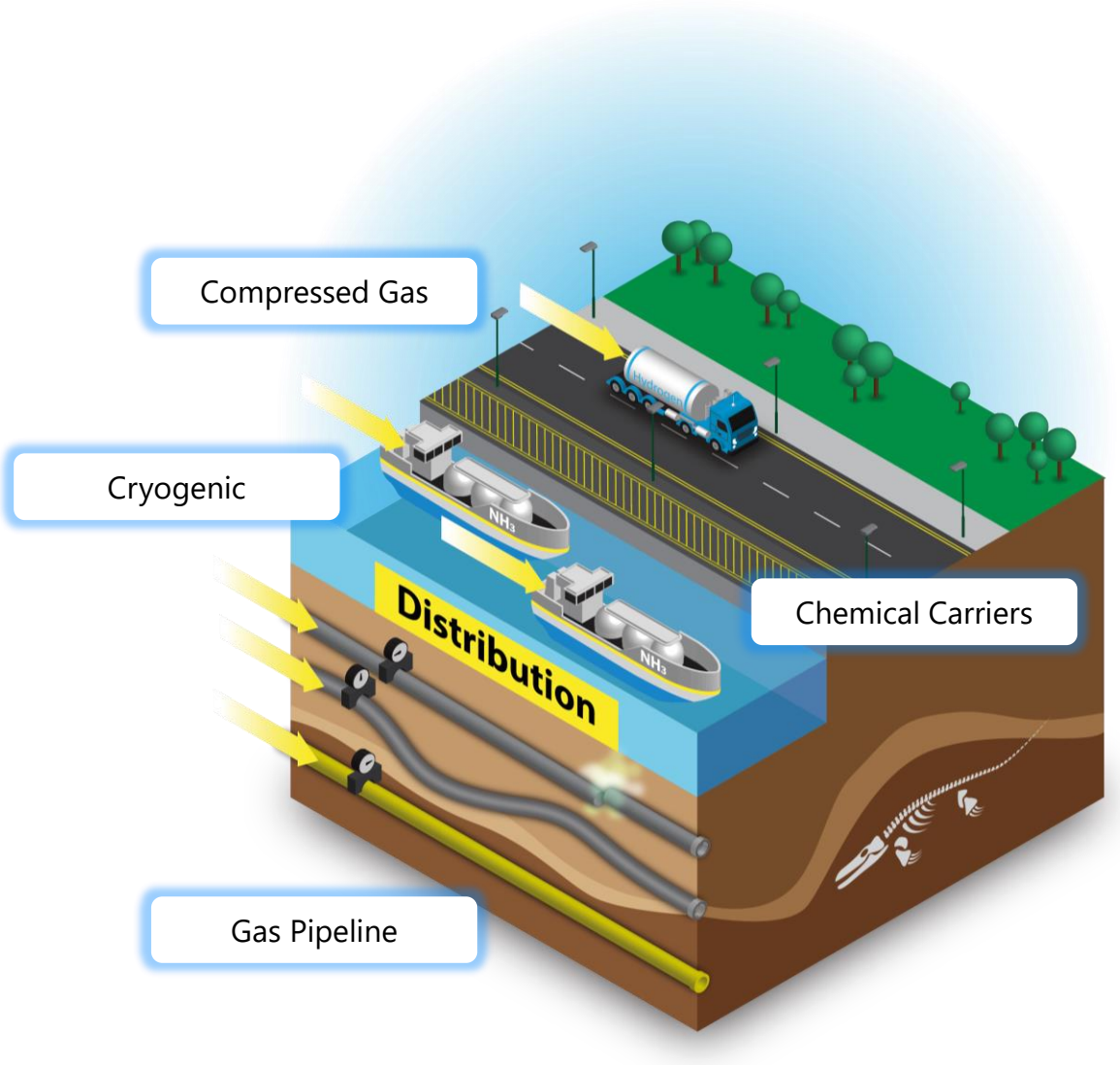


- Able to use isotopic labelling of CO to monitor poisoning processes inside of operating devices
- Performance loss when anode catalyst is covered more than ~ 30% by CO

Becker, Hans, et al. "Operando characterisation of the impact of carbon monoxide on PEMFC performance using isotopic labelling and gas analysis." Journal of Power Sources Advances 6 (2020): 100036.

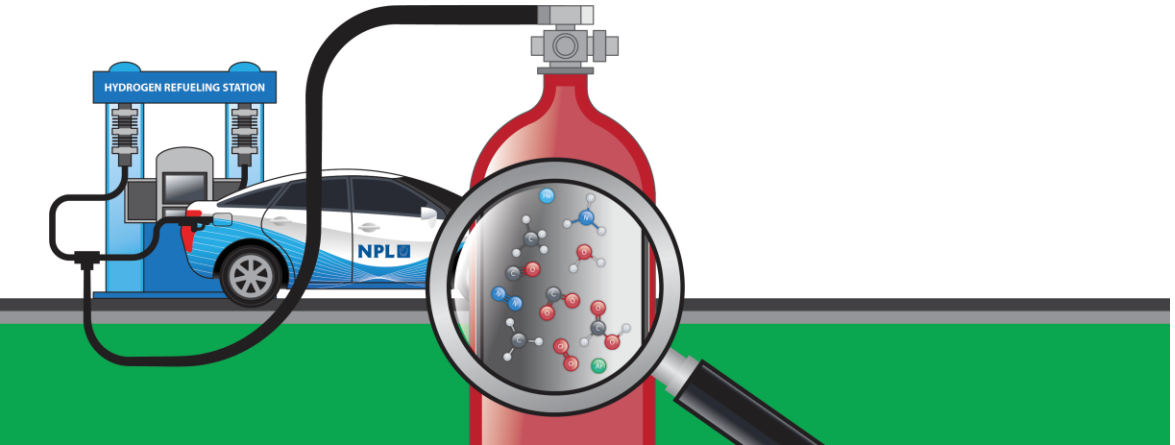
Impurity Sources

- Impurities depend on mode of production
  - Electrolysis
  - Methane reforming
  - Biomass
- & mode of storage and distribution
  - Hydrocarbons, ammonia, methane, biological materials
  - Blending?



Hydrogen Quality Assurance

Sampling Location	n.a.	Hydrogen Refueling Station—700 Bar	FCEV Sampling—1
Sampling system	n.a.	H2 Qualitizer	NPL prototype
Sampling vessel	n.a.	10 L cylinder aluminum Spectraseal	10 L cylinder aluminum Spectraseal
Compounds	ISO 14687:2019 threshold (µmol/mol)	Measured amount fraction and expanded	(k = 2)/(µmol/mol)
Nitrogen	300	24.7 ± 0.7	25.0 ± 0.6
Helium	300	<14	<14
Argon	300	0.870 ± 0.035	0.835 ± 0.031
Water	5	1.27 ± 0.26	4.4 ± 0.9
Oxygen	5	<0.5	<0.5
Carbon dioxide	2	<0.020	<0.020
Methane	100	<0.020	<0.020
Non-methane hydrocarbons	2	<0.040	<0.040
Carbon monoxide	0.2	<0.030	<0.030
Formic acid	0.2	<0.040	<0.08
Ammonia	0.1	<0.07	<0.07
Formaldehyde	0.2	<0.05	<0.05
Total halogenated compounds[1]	0.05	<0.032	<0.030
Individual organo halogenated compounds [2]	n.a.	<0.0030	<0.0030
Total sulphur compounds [3]	0.004	<0.0010	<0.0030

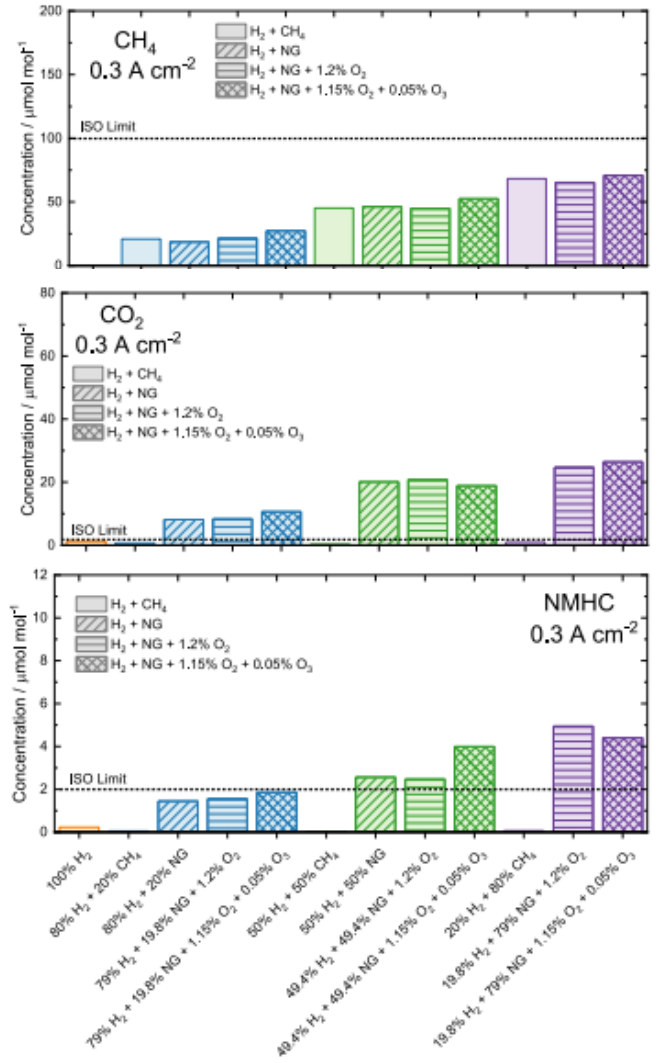


- Sample from a HRS, vehicle, process
- Use a range of analytical measurements to determine purity
- HRS are generally compliant but there are periodic quality issues reported

Bacquart, Thomas, et al. "First Hydrogen Fuel Sampling from a Fuel Cell Hydrogen Electrical Vehicle–Validation of Hydrogen Fuel Sampling System to Investigate FCEV Performance." Processes 10.9 (2022): 1709.

Purification

- Well established deblending and purification technologies
- Many have a high OPEX (& CAPEX) when considering small scale / HRS
- Some novel technologies being developed but unproven



Jackson, Colleen, et. al.. "Deblending and purification of hydrogen from natural gas mixtures using the electrochemical hydrogen pump." *International Journal of Hydrogen Energy* 52 (2024): 816-826.

Two Key Messages

1. Hydrogen quality is important consideration when considering supply of hydrogen

2. Hydrogen may be available everywhere in 2035 but not necessarily of quality for PEMFC

Acknowledgements

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MefHySto
Metrology for Advanced Hydrogen Storage Solutions

METROLOGY for HYDROGEN VEHICLES 2

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