# RD&D Supporting Ammonia Energy Systems

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Australia's National Science Agency

CSIRO

# Overview

CSIRO and our hydrogen and ammonia RD&D

RD&D Snapshots:

- Ammonia synthesis
- Utilisation: engines and fuel cells
- Cracking for UHP $H_2$ production
- Emerging use cases

Ongoing challenges:

- Tech development, cost reduction, scale
- Practical challenges

# Background and context

# Decarbonising Energy

## Renewables

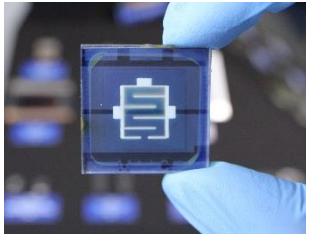
- Hydrogen and carriers, solar PV, solar thermal and bioenergy for power and green heat
- New technologies, hybrid systems, and solutions development
- Derisking new pathways and value chains

## Industrial Decarbonisation

- $CO_2$ capture from industrial processes … and the air
- $CO_2$ utilisation pathways
- Alternative fuels (e.g. SAF), $H_2$ integration

## Circular Economy

- Battery second life and recycling
- Waste management, energy recovery, and advanced recycling



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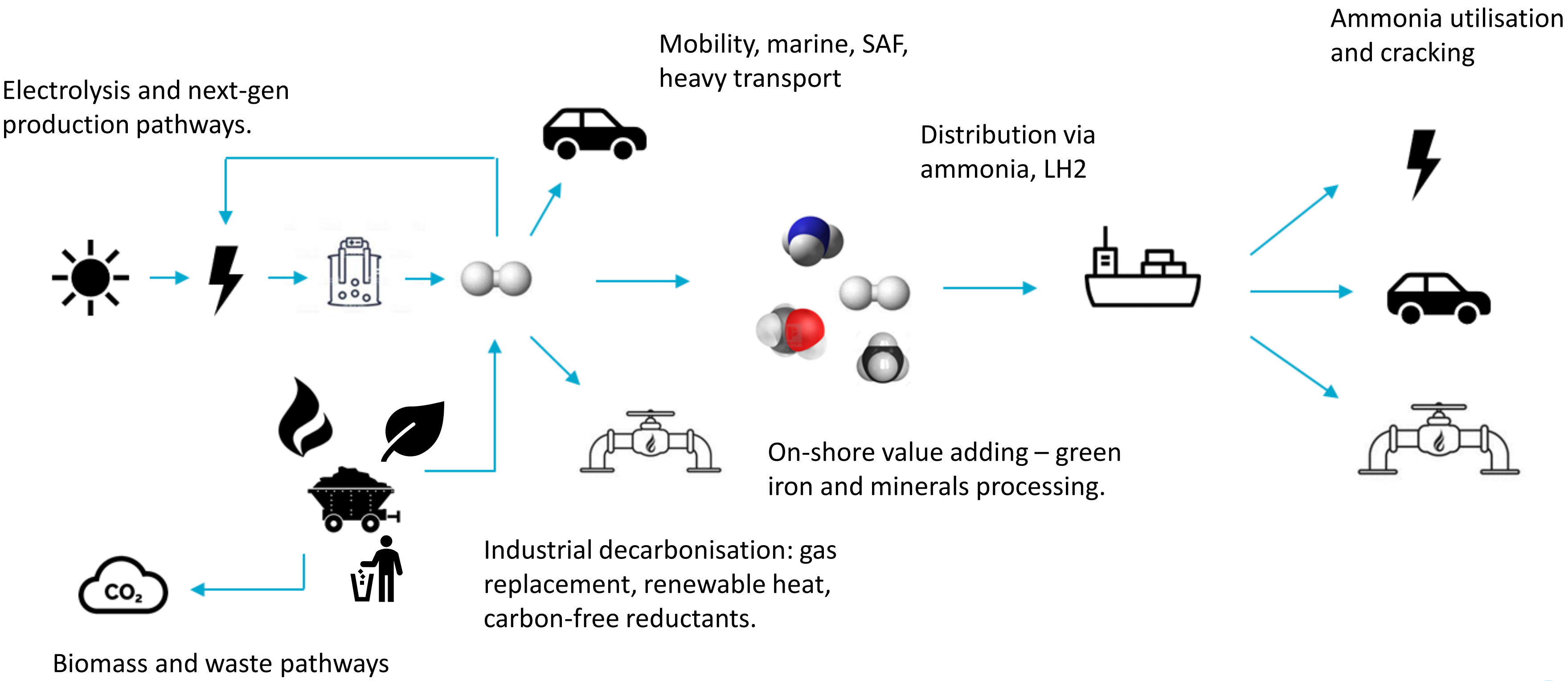
# Hydrogen energy RD&D




Coordinating and enabling initiatives: Hydrogen Industry Mission, Hydrogen Energy Future Science Platform

# Ammonia as a hydrogen energy carrier

## RD&D supporting a range of new ammonia pathways

New technologies emerging to support distributed, efficient ammonia production

Cracking back to fuel cell grade $H_2$

Direct use in engines, turbines, and boilers

Direct use in fuel cells

Non-energy applications: fertiliser, reductant

Utilisation pathways to address specific end-use needs

# RD&D Snapshot

## Synthesis, utilisation, cracking, emerging opportunities.

# Activities spanning the TRL spectrum

## Enabling technologies being developed and commercialised

- Commercial demonstration examples (building on success of initiatives such as Endua):
  - Integrated cracking & hydrogen separation technology (with FFI)
  - Ammonia engines for industrial power
- Proof of concept prototyping
  - Ammonia synthesis (Orica, GRDC)
  - Ammonia fuel cells
- Next generation concepts
  - Plasma-assisted synthesis
  - Direct use in iron production applications

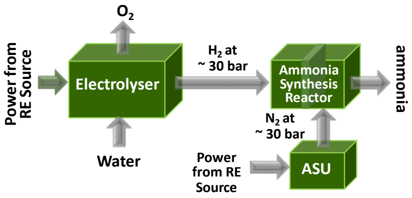

# Green ammonia production

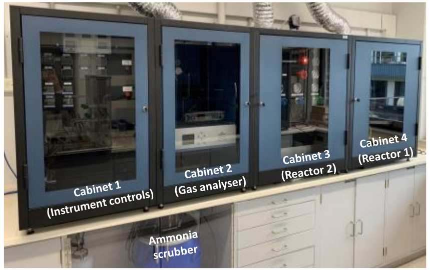
## Overview:

- Membrane based technology
- Rates similar to the conventional Haber-Bosch process but at less than 1/5th the pressures.
- Technology amenable for distributed scale production of green ammonia by sourcing hydrogen from electrolysers.
- Technology successfully demonstrated at kg/day scale in CHES as part of the ARENA (2018-2022) project advancing to TRL 6, with substantial IP and know-how generated on concept, process and reactor design.

## Recently completed a project (2022-23) funded by GRDC:

- Upgrading the rector design and demonstrating green ammonia production by using hydrogen produced by a solar PV integrated electrolyser.
- Techno-economic analysis  of  green ammonia production by CSIRO and H-B technologies.
- Exploratory work on alternative low-cost metal membranes




CSIRO Technology concept and demonstration rig

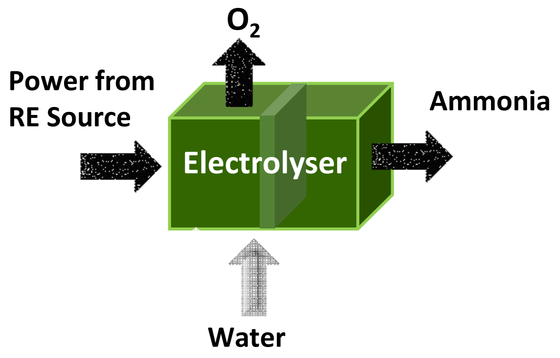
ORICA GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION Australian Government Australian Renewable Energy Agency ARENA CSIRO

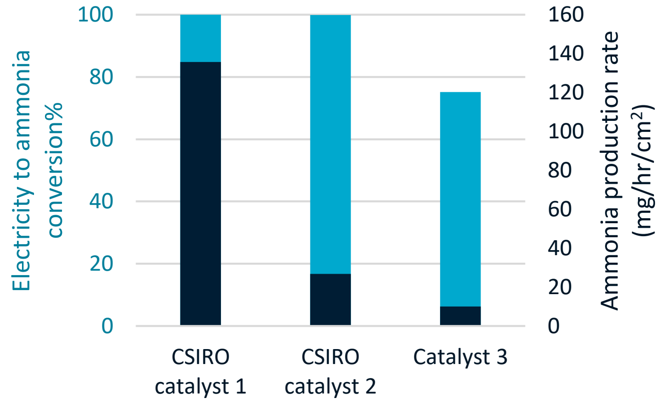
# Plasma-assisted electrochemical ammonia synthesis

Water and air are the only inputs for the single-step, atmospheric pressure process.

Modular in nature makes it suitable for small to medium scale.

Existing know-how on PEM / alkaline/Solid oxide electrolysis on the cell / stack designs and BOP that can be easily transferred to this technology.




DOE target for green ammonia production – 57 mg/cm$^2$/hr


1. E (2016) REFUEL Program

2. Giddey et al., Int J Hydrogen Energy, 38 (2013) P14576

# Ammonia and the reciprocating engine

Reciprocating engines have thermal efficiencies ranging from 42% to over 55%

- Fuel quality tolerance, flexibility, low cost and longevity

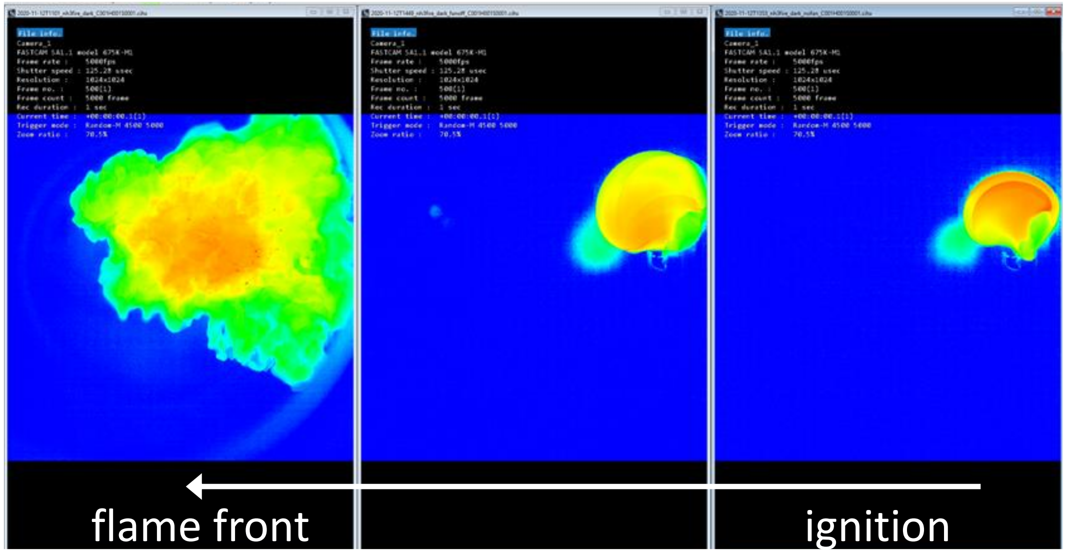
Low-medium speed (50-1000 rpm) engines can give comparable performance to fuel oils, and slightly higher than for natural gas

- Potential for major $CO_2$ savings, especially for applications requiring extensive fuel storage
- The extensive use of medium speed, medium size reciprocating engines (10-24$MW_e$) for stationary generation (superior to gas turbines) is the enabler
- Highly suitable for backup and load balancing to support a high uptake of RE

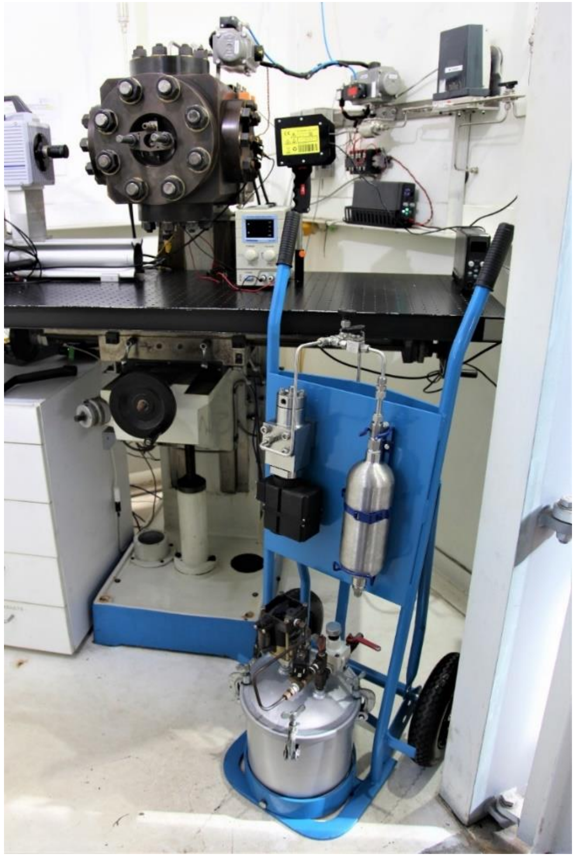

20MW each – V18 MAN (fuel oil engines)

# Combustion fundamentals:
## Ignition and spray combustion chamber

Homogeneous or spray combustion testing ongoing for $LNH_3$ and mixtures at up to 200 bar




Homogeneous (premixed) combustion



spray combustion

# Ammonia generator demonstration facility

## 500-750 kW ammonia engine

Staged Proposal – early demonstration, incremental optimisation of technology and operating strategies:

**Stage 1: Minimal adaptation - dual fuelling**

- Low/medium speed (500rpm) engine and generator system
- Engine adaptations to allow dual fuel operation with up to 95% diesel replacement

**Stage 2: Optimisation of performance**

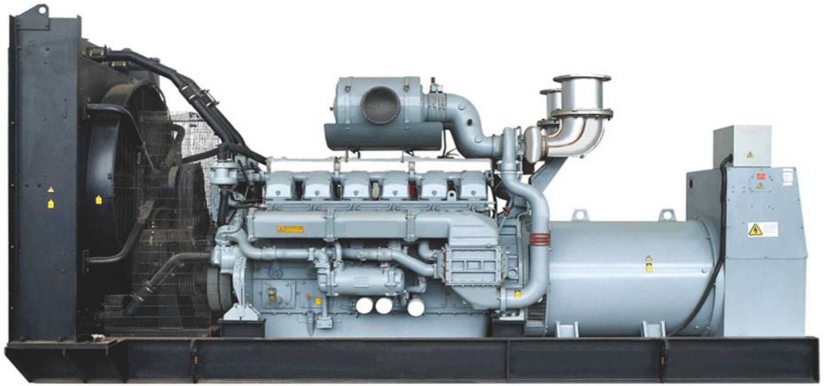
- Fuelling control
- Start-up and shutdown strategies
- Emissions control equipment and operating strategy

**Stage 3: Full diesel replacement scenarios**

- Biofuel-ammonia, and/or 100% ammonia

**Stage 4: Next generation engines**

- High compression engines specifically designed to exploit ammonia's unique properties
- Higher speed (1500rpm) engines
- Multi-fuel systems  to maximise synergies with biofuels



Generic example only : 500kW commercial generator

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# Ammonia fuel cells

Converting ammonia into electricity in a single step, with very high efficiency.

**SOFC**

## Current focus

- High-performance anode electrode and electrolyte
- Demo of a 1 kW fuel cell module.

Test rig station

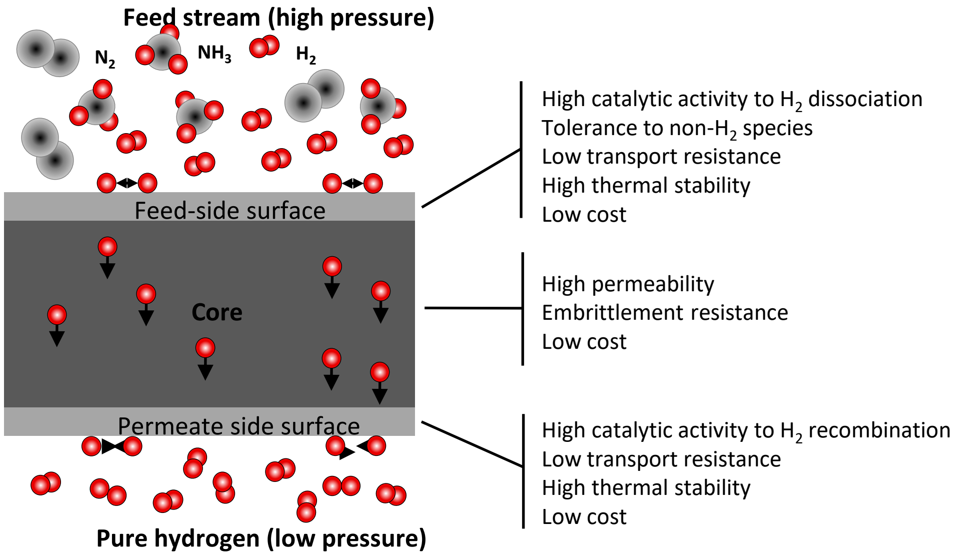
## Achievements

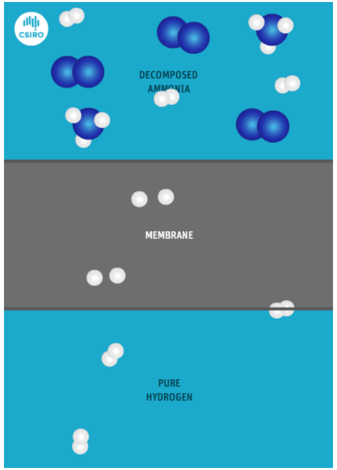
- Test station capabilities developed
- Long-term cell operation up to 1000 hours, Can test cells of dimension 8 mm dia. to 80 mm diameter.
- Can test various cell geometries.

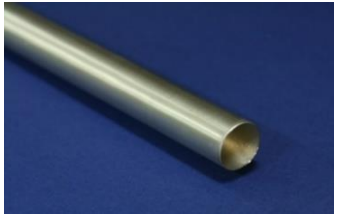
# Metal Membrane Technology
## production and separation of high purity hydrogen

Separation of $H_2$ from ammonia-derived mixed gas streams

This concept can also be applied to NG reforming, CO shift, or any process with $H_2$ as a product.



# Pilot scale Ammonia Cracking Facility

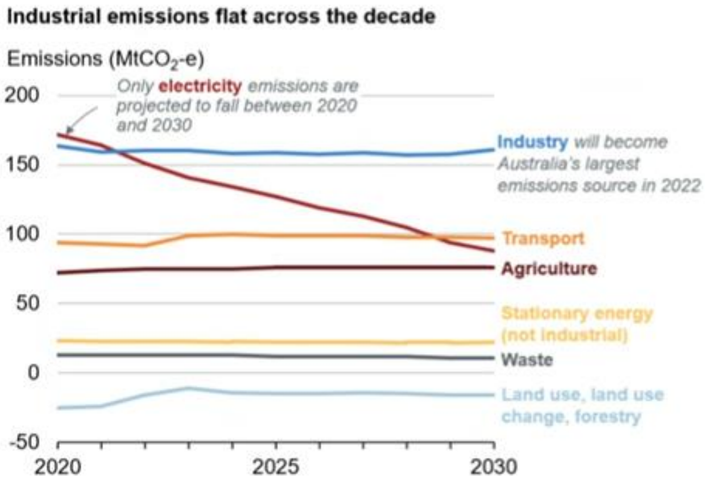
Gen 1 system (SIEF funding):

- 15 kg/day
- 2-3 cars/day
- Located at CSIRO Brisbane, commissioned 2018

Gen 2 Plant (FFI commercial partner):

- 200kg/day $H_2$ production
- Development and demonstration facilities supporting commercial development


# Industrial emissions remain a challenge




Courtesy Tony Wood, Grattan Institute
Presentation to HILTCRC, 4 Aug 2022

Electricity emissions are expected to fall over coming decade

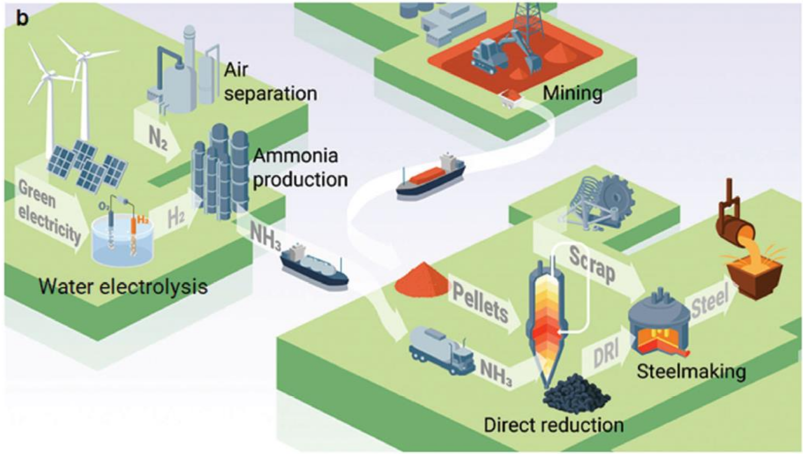
- Closure of carbon intensive generation
- Increasing penetration of solar and wind

Industry is expected to become our largest emitter of $CO_2$.

# Iron production using ammonia as a reductant

Project aims are to:

- Explore the fundamental behaviour of ammonia as an iron ore reductant
- Investigate the conditions required for ammonia direct reduction and the parameters affecting the reactions through thermodynamic analysis and kinetics studies involving ammonia injection in laboratory scale shaft and/or fluidised bed reactors,
- Examine the reduction mechanisms of ammonia DRI and develop a model for the process characteristics
- Propose a suitable industrial-scale reactor design




(Ma et al., 2023)

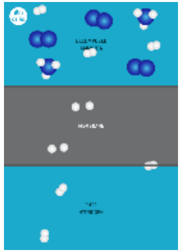
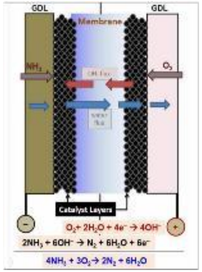
# Summary

# Plenty of work still to do:
## RD&D focus areas supporting the energy transition

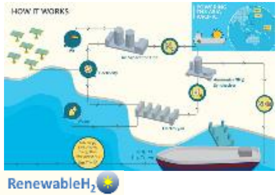
### Cost reduction
- New technologies, reducing process steps

### Diversification
- Sector coupling
- New technologies and pathways

### Demonstration
- Derisking value chains and supporting industry
- Technology familiarisation, industrial-scale challenges
- Practical considerations
  - As a marine fuel: moving from shiploading to shiploading plus bunkering.
  - Bulk storage of $NH_3$, repurposing infrastructure.
  - Permitting etc – safety, environment. There is knowledge available, but needs to be 'translated' or applied for specific industrial applications.



# Thank you

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