

Hydrogen Energy Value Chains:
Ammonia as an enabling hydrogen carrier

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CSIRO ENERGY
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Outline

CSIRO - Australia's national research agency

Hydrogen re-emerging as a clean energy carrier

New science and technology opportunities

- Leveraging existing industries and infrastructure

Hydrogen energy value chains - amplifying the impact of renewables

- Low emission pathways for power, manufacturing, transport
- Challenges of scale
- Ammonia's role as an energy bridge

CSIRO

Commonwealth Scientific and Industrial Research Organisation

People	5000
Locations	55
Business Units	9
Budget	$1B+

CSIRO Low Emissions Energy Research

R&D supporting the transition to a high efficiency, low emissions energy future

Emissions Management and CO_2 capture

- Emissions characterisation, reactions & impacts
- CO_2 capture technologies for current and next generation energy systems
  - Post combustion capture (PCC), membrane systems (CO_2/H_2,CMR systems)

Thermal and Electrochemical Technologies

- Next-generation technologies for coal & renewable fuels
  - Gasification, DICE, Fuel Cells …
  - Waste to Energy (biomass, MSW etc)
  - ***Hydrogen energy systems – renewable and fossil fuel sources***
- Hybrid Energy Systems
  - Batteries, fuel cells, electrolysers, energy storage, system integration

Solar Energy Systems

- Solar Thermal systems for power generation, energy storage, hybrid processing technologies
- ASTRI - ~$120M collaborative program: CSIRO, 6 Universities, International partners
- PV materials and cell design

Hydrogen energy value chains

H_2 2019: What's changed?

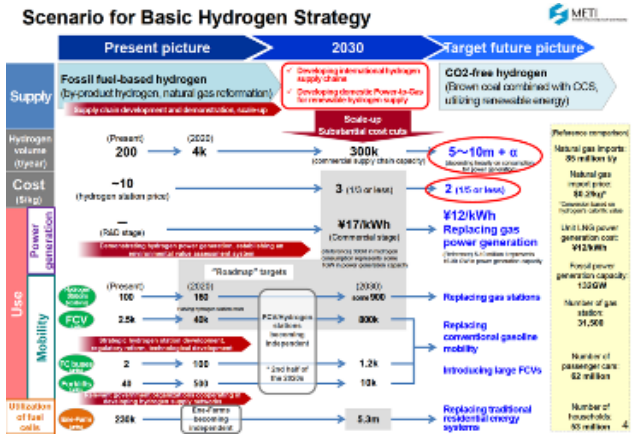
Global market pull

- Japan's 'Basic Hydrogen Strategy'
- Korean hydrogen roadmap
- EU initiatives and demonstrations

Technology developments and advances

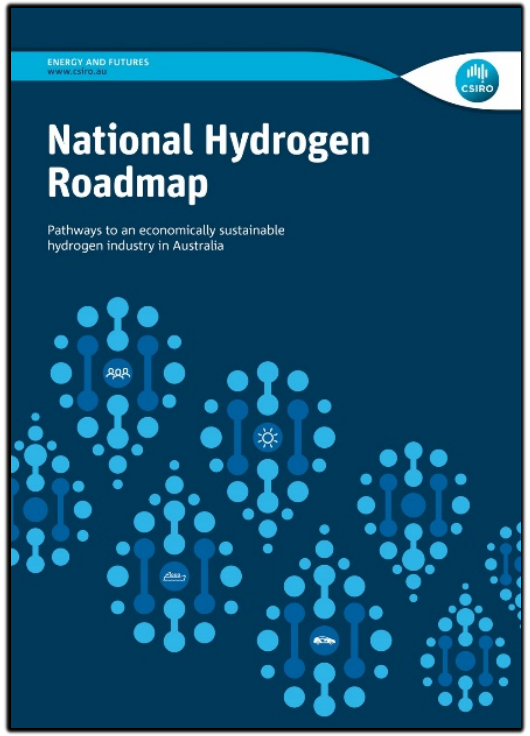
- FCEVs: Range increasing, cost decreasing
- Electrolysers, PV electricity, etc: cost decreasing
- Carrier technologies: ammonia cracking, hydrogen tankers, new materials

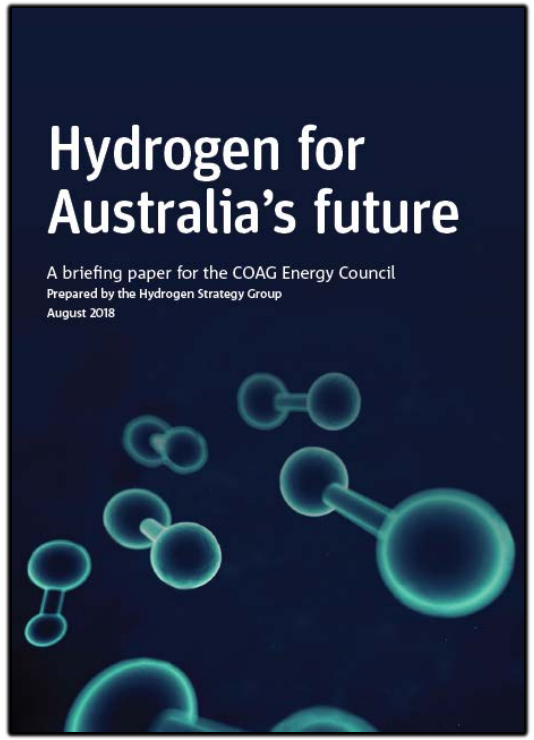
Increasing acceptance of energy alternatives across sectors (including governments).

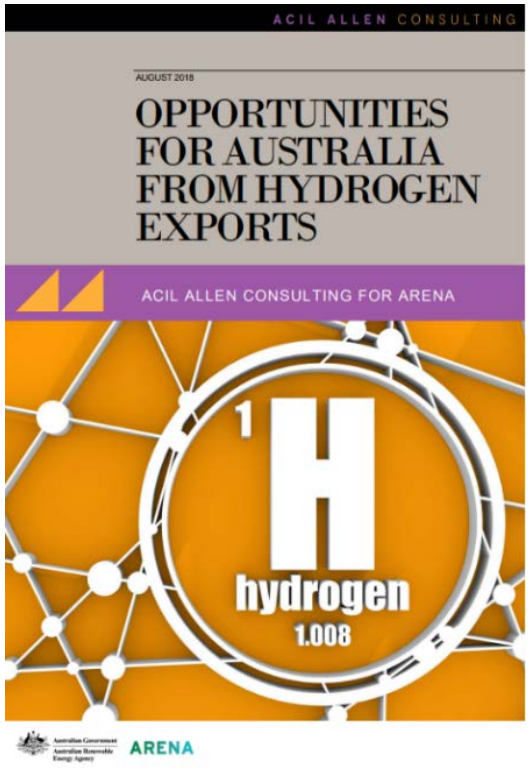


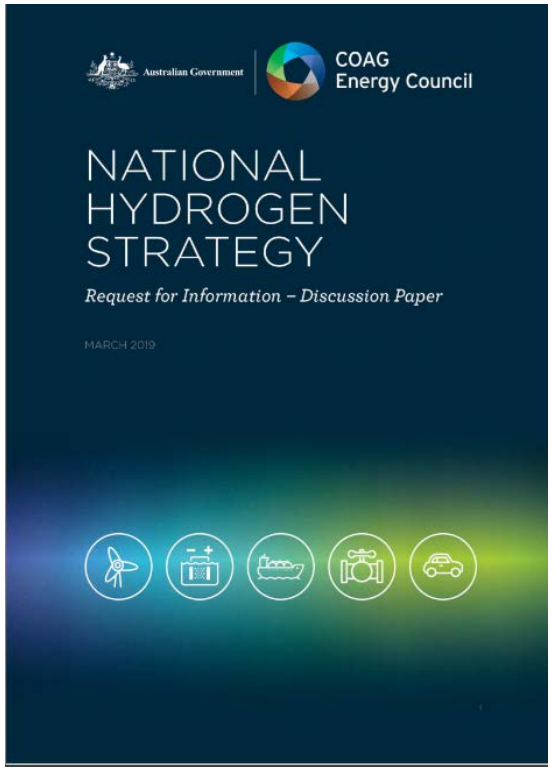
Increasing National Focus

Development of an Australian hydrogen energy industry



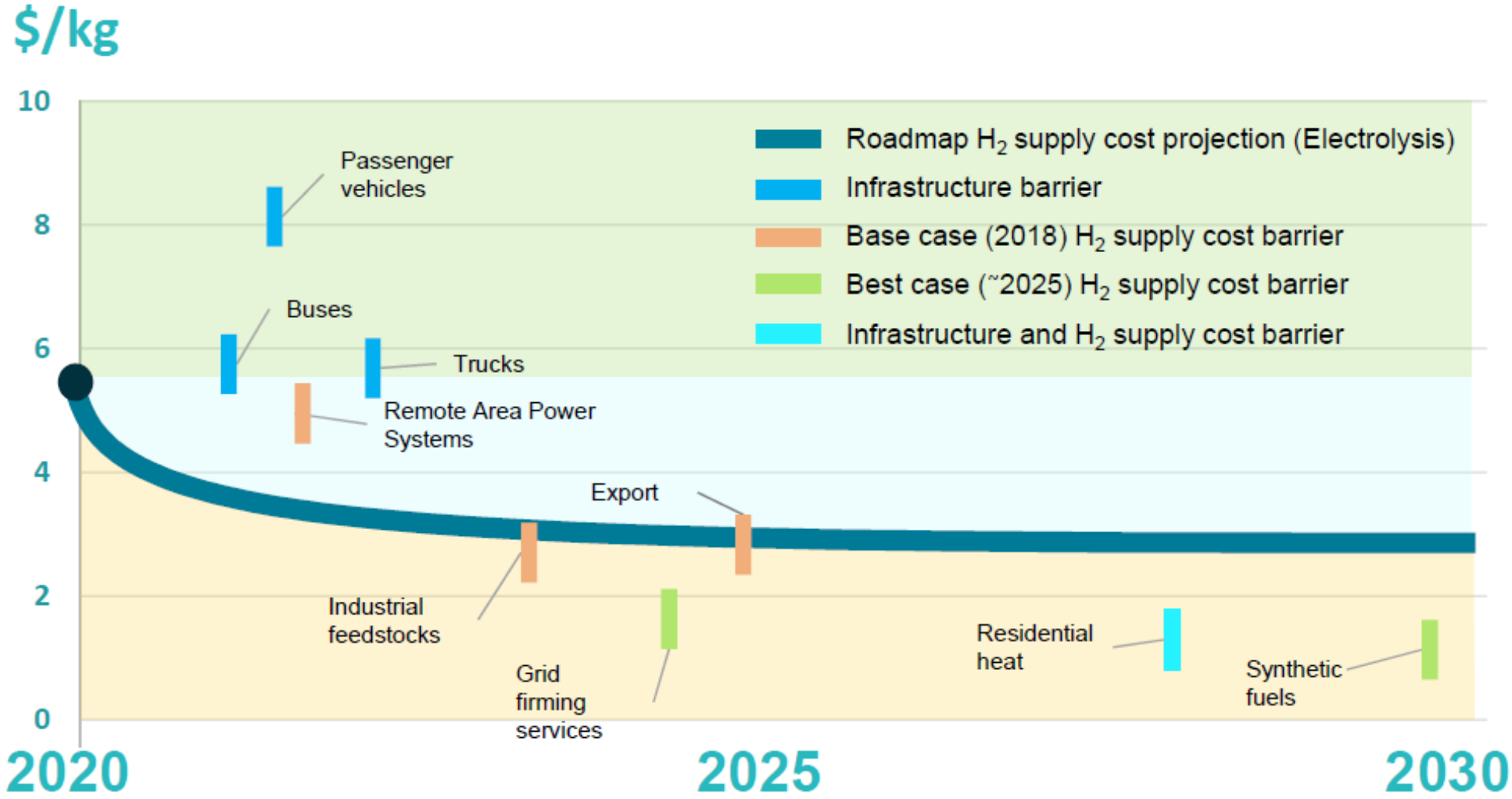






"Hydrogen could be Australia's next multibillion dollar export opportunity"
Prof Alan Finkel, Aug 2018

Hydrogen Cost* Implications

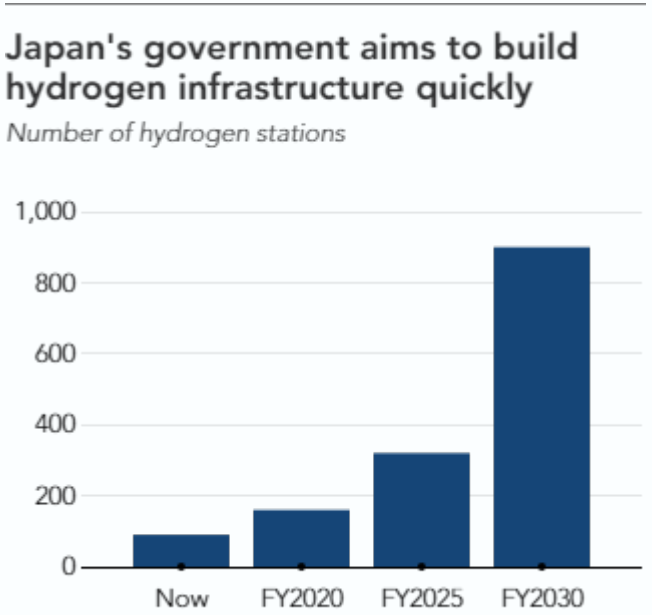


- Many H_2 technologies are commercially mature.
- Market Activation is a key priority
- Requires infrastructure and hydrogen supply
- Export opportunities support scale and cost improvements

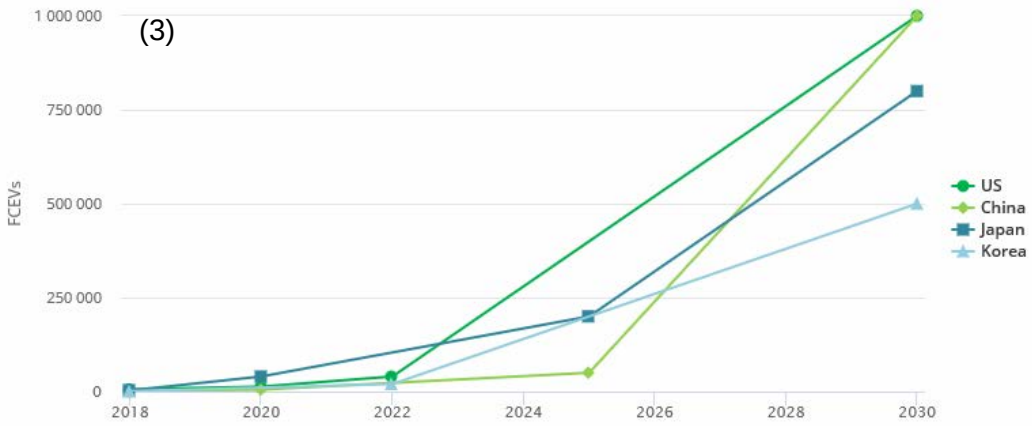
* Cost of hydrogen production by electrolysis (~6c/kwh)

Japan and Korea focus on supply chains, infrastructure and scale

- Japan[1]:
  - Hydrogen stations cost approx ¥400- 500M (US$3.8 M to $4.7M) to build.
    - Government contribution 50%
    - Seeking to halve cost by 2020
    - Facilitating incorporating hydrogen stations into Japan's existing 31,000 gas/petrol stations



- Korea[2]:
  - Target 1200 FCEV refuelling stations by 2040
  - FCEV manufacture – 80,000 by 2022, 6.2M by 2040
  - By 2040: 40,000 FC Buses; 30,000 Trucks; 80,000 Taxis



Source: (1) - Nikkei Asian Review, March 2019), (2) – Hydrogen Economy Roadmap, MTIE Korea, June 2019, (3) - IEA

Australian Hydrogen Energy Initiatives…

Several intersecting value chains

Hydrogen Energy Supply Chain Project

- Low emissions hydrogen from coal gasification with CCS

CSIRO hydrogen production, storage, transport and utilisation technologies

- Novel technologies for H_2 and NH_3 synthesis
- Ammonia cracking technology
- Direct ammonia utilisation (engines and fuel cells)

CSIRO Hydrogen Energy Systems Future Science Platform

- Step change technology opportunities across the value chain
- ~$5Mpa, 3years, collaborative forward looking science & technology opportunities

ARENA - Renewable Hydrogen for Export Research Fund

- $22M for hydrogen energy supply chain technology research

Hydrogen Mobility Australia

- Industry initiative to accelerate commercialisation of hydrogen technologies

Industry-scale projects and demonstrations – e.g. ATCO, FMG, Gladstone, Toyota….

The Hydrogen Value Chain

Building on existing industries and infrastructure

Make it → **Move it** → **Use it**

Hydrogen Value Chain(s)

Complex network of opportunities











Make it

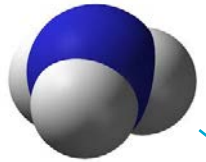
Store/
Move it

Use it

Enabling H_2 energy systems

Reducing cost of electrolysis

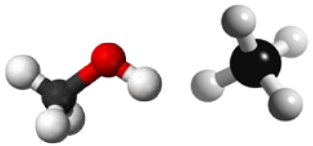
Scalable, intermittency-friendly NH_3 production



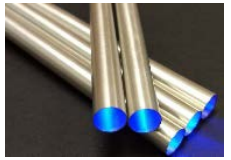
New renewable energy export industry

Decarbonisation of heavy transport and distributed power

Gasification routes for coal, biomass & wastes to hydrogen



Other carriers: methanol, SNG…

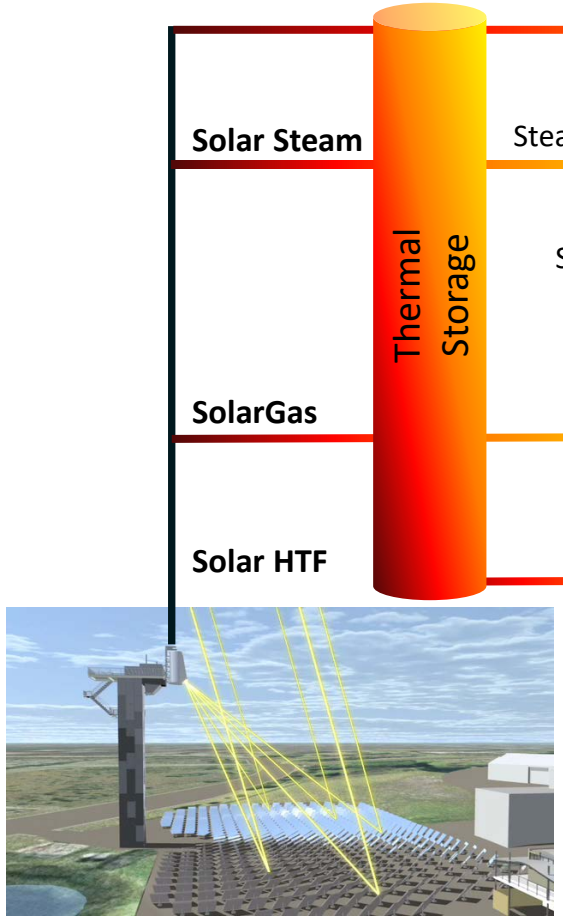


H_2

Ammonia cracking for decarbonisation of vehicle transport systems

Concentrated Solar Thermal technologies

Integration of solar energy in thermal and chemical processes



Heliostat and Receiver Technologies

Solar Steam

SolarGas

Solar HTF

Thermal Storage

Industrial process heat

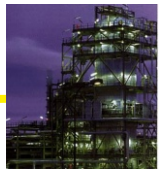
Steam turbine

Electricity

Shift Reactor

$CO_2 + H_2$

Hydrogen production



Liquid transport fuels via Fischer Tropsch or Methanol

Air

Electricity

Gas turbine – simple or combined cycle

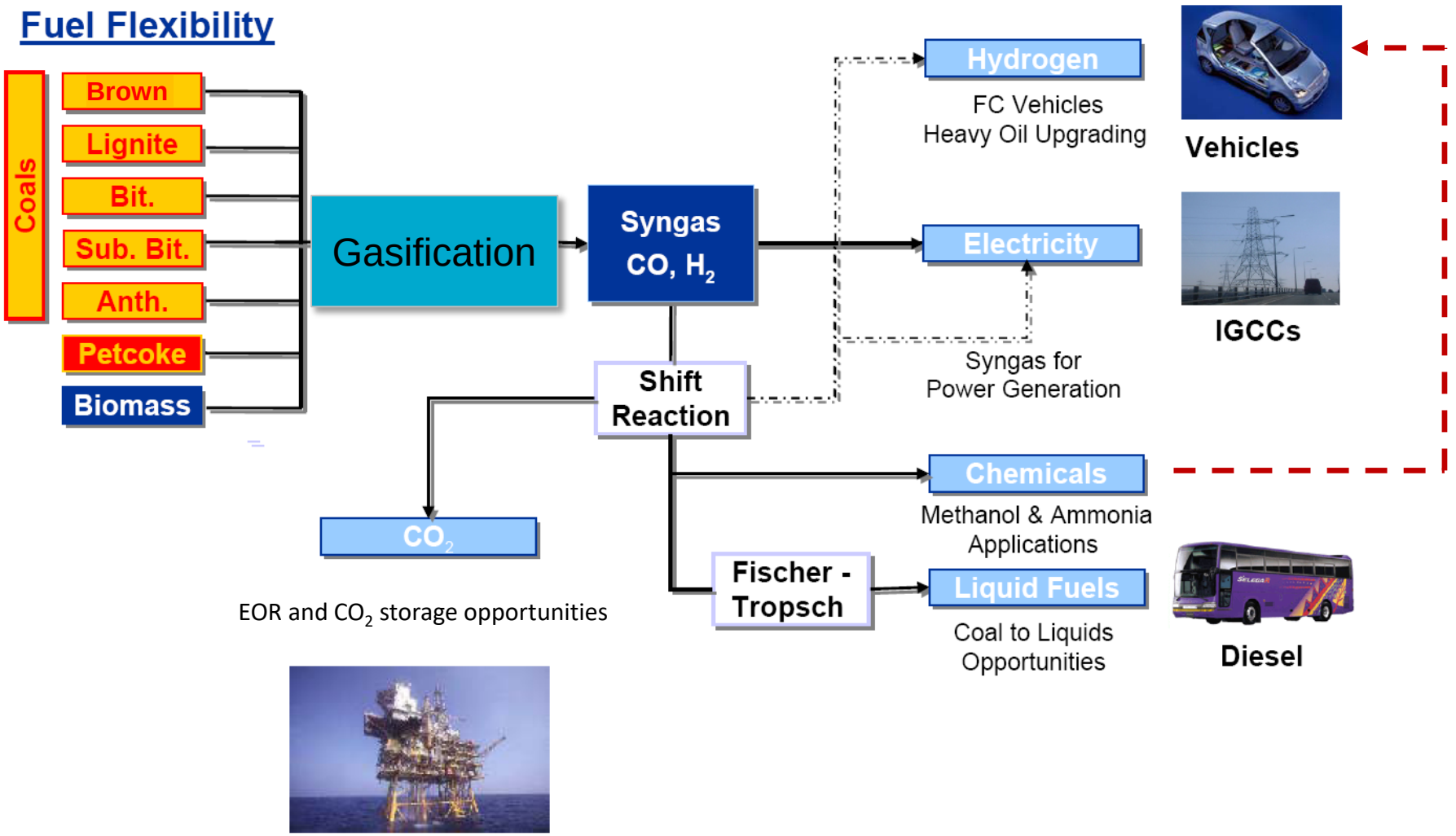
Supercritical CO_2

Electricity

sCO_2 Brayton Cycle

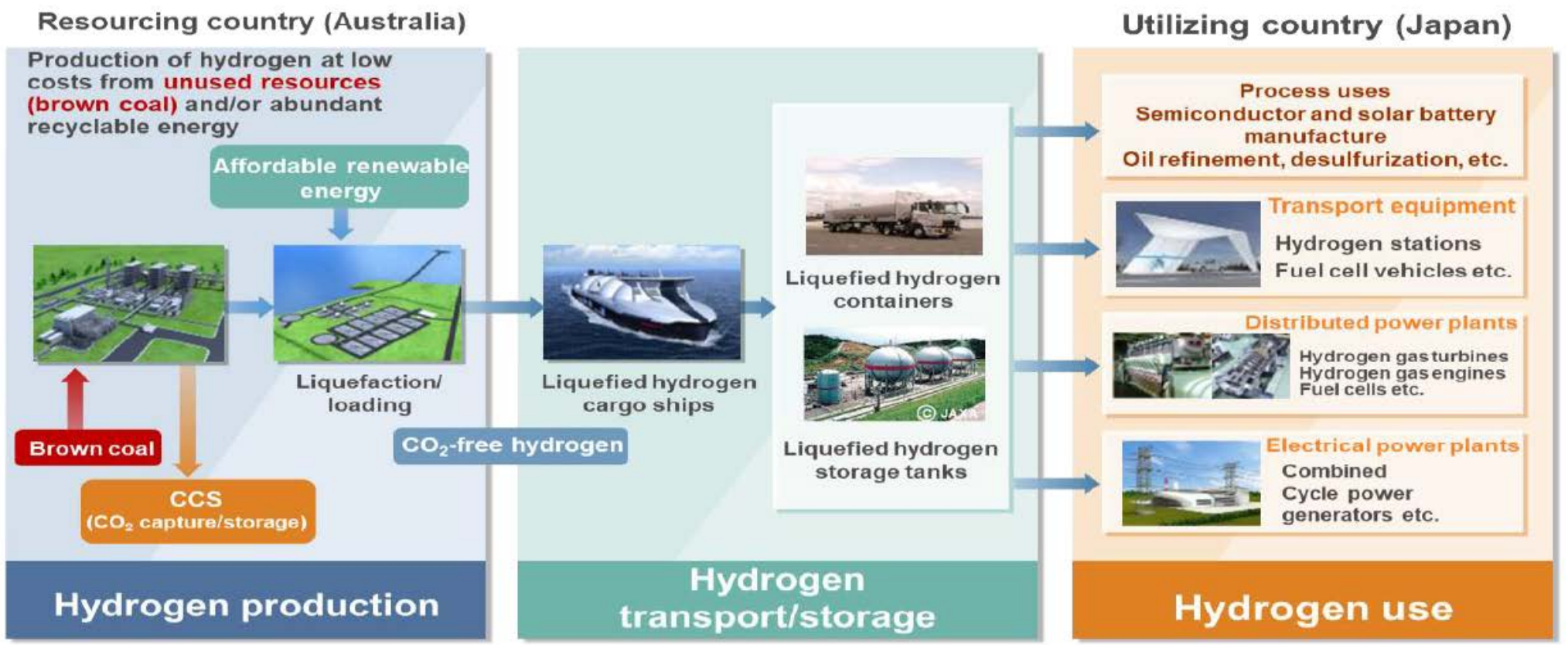
SMR & WGS processes
Solar syngas and H_2
25% solar energy embodied
Pilot scale demonstrated to $600kW_{th}$

Gasification: a flexible enabling technology



Source: Shell 2007

KHI "CO_2 free hydrogen chain"
Gasification of Australian brown coal with CCS



29.8 yen/Nm^3

Hydrogen carrier	9%
Loading base	11%
Hydrogen liquefaction	33%
Hydrogen pipeline	1%
Hydrogen production	29%
CCS	10%
Brown coal	8%

Hydrogen capacity: ~770 tonne/day

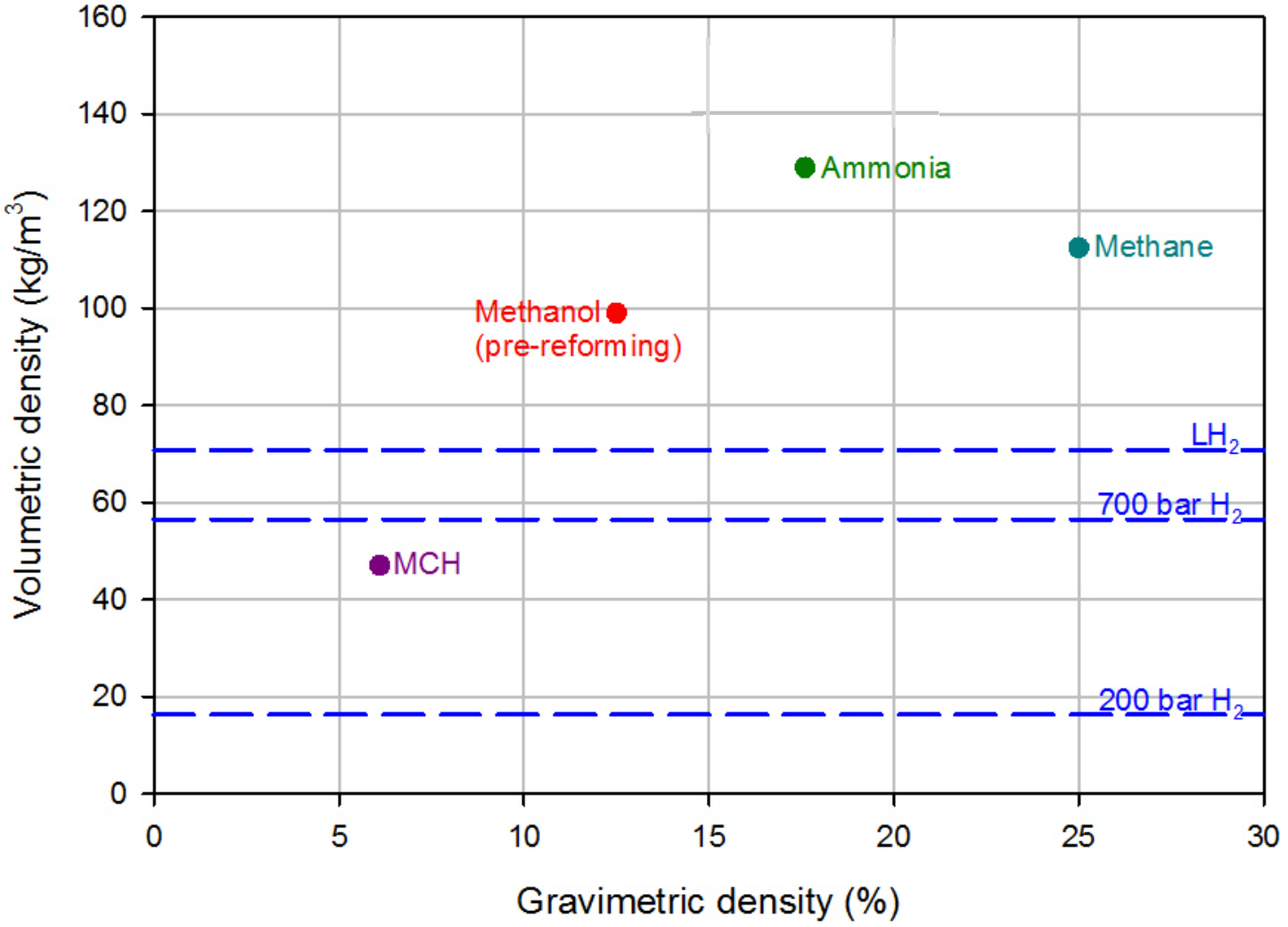
Source: https://www.mizuho-ir.co.jp/publication/report/2016/pdf/wttghg1612.pdf

Make it

Move it

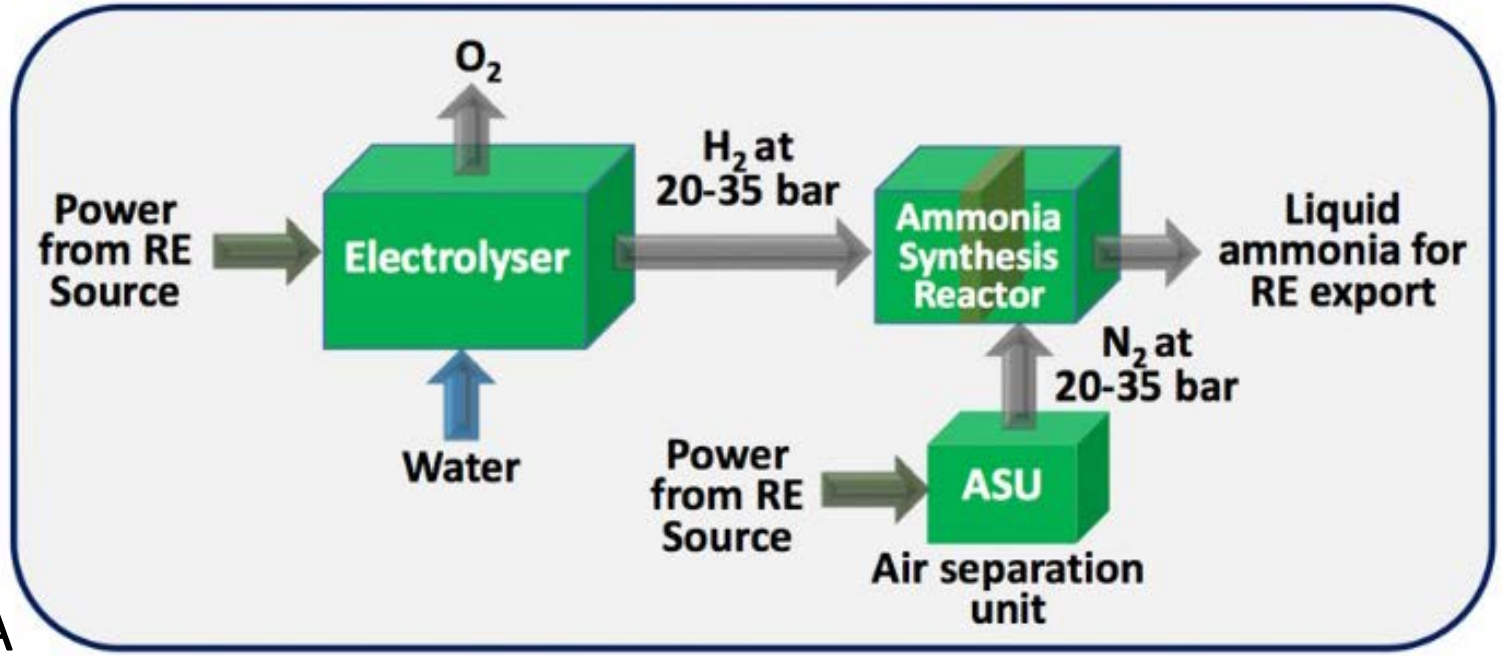
Use it

CO_2-neutral hydrogen carriers



Novel direct ammonia production technology
catalytic membrane reactor

- Prototype proof of concept facility developed
- Low pressure (10-30bar)
  - ~25% lower energy input than Haber Bosch process
- Decentralised, modular process
- High conversion rate and yield
- Collaborative project with ARENA support (~$2.8M project)
- Project partners: Orica, GRDC, ARENA, CSIRO



ORICA

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

Australian Government
Australian Renewable Energy Agency

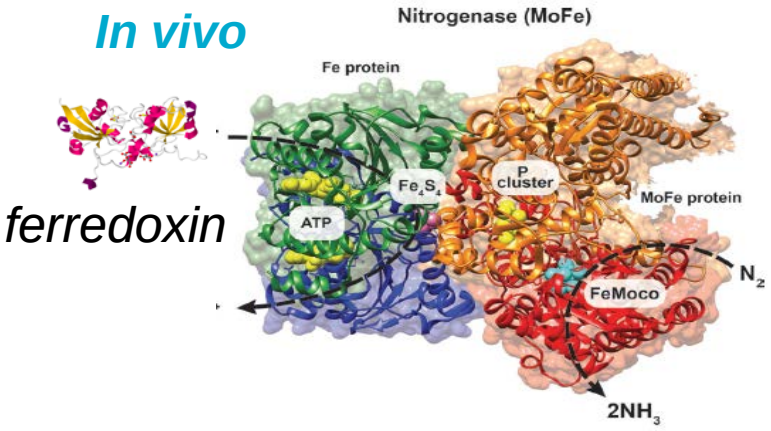
ARENA

CSIRO

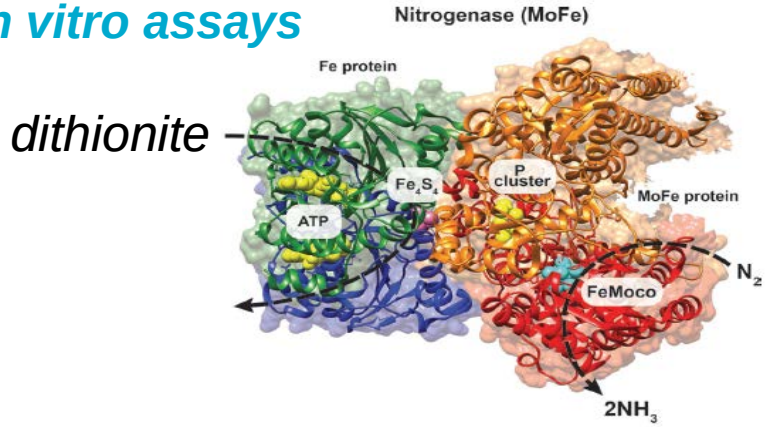
A route to solar powered nitrogenase

Harnessing biological pathways for ammonia production

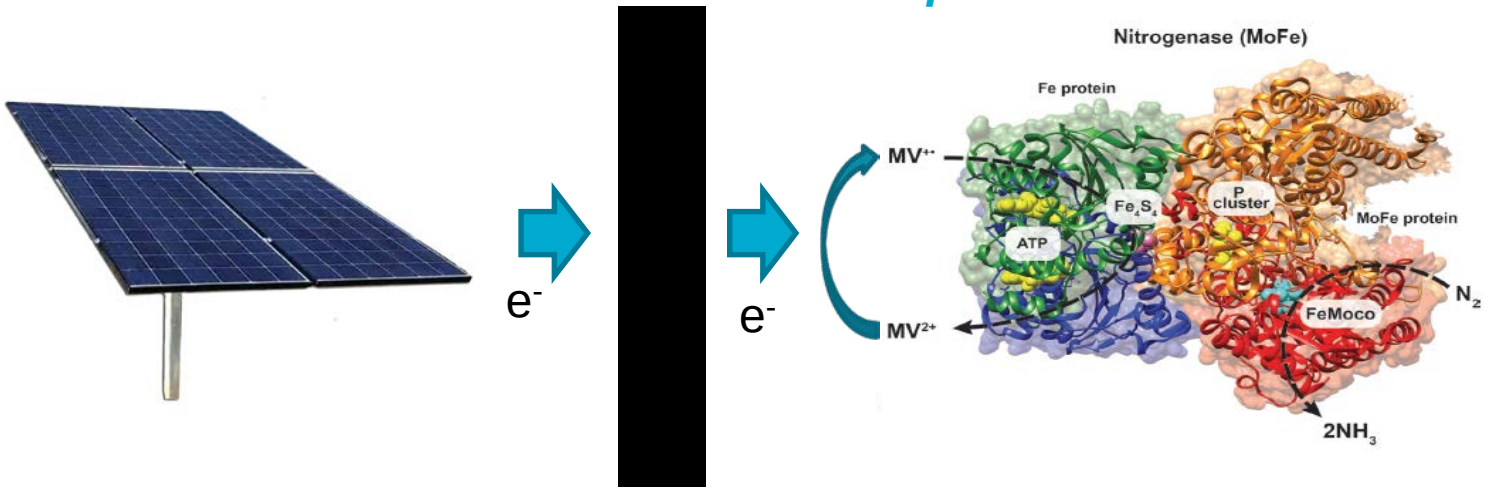
In vivo



In vitro assays



Solar powered



Source: Trevor Rapson, Craig Wood – CSIRO Ag and Food

Make it

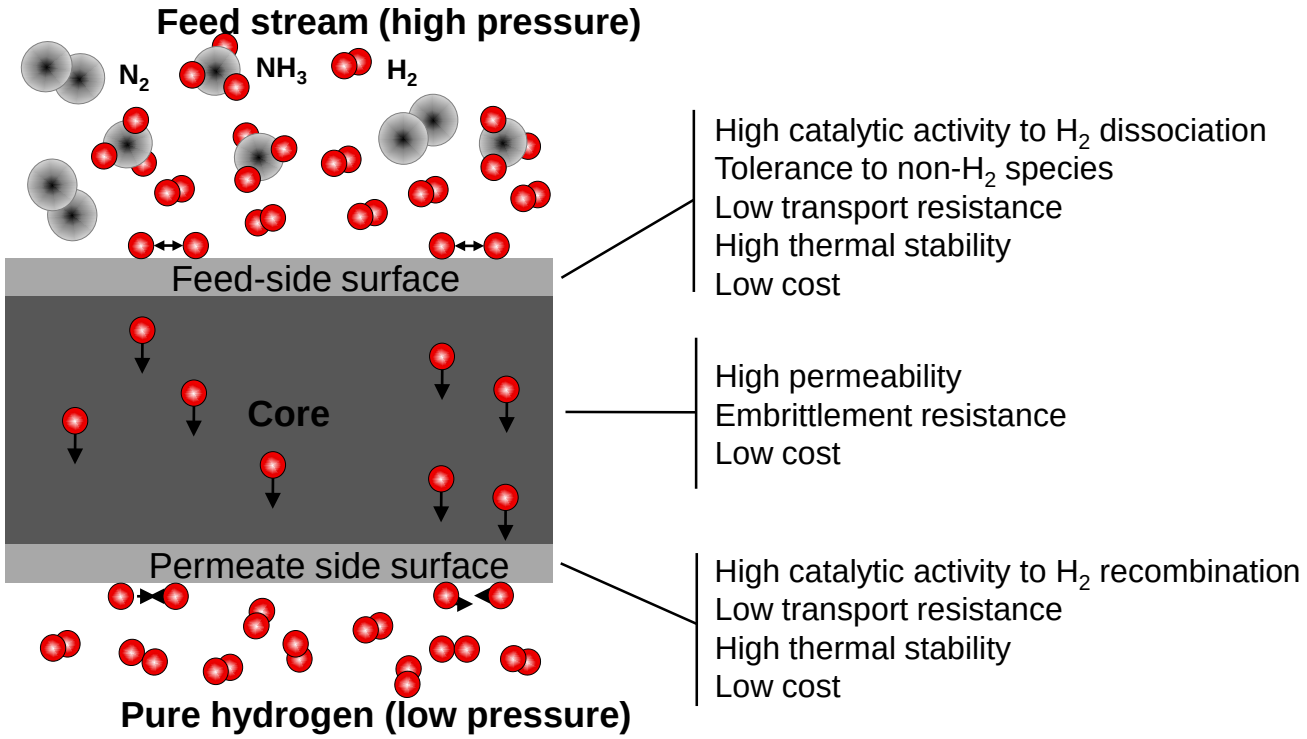
Move it

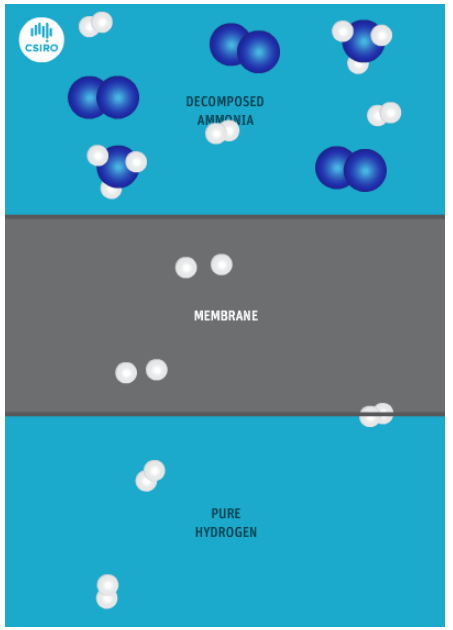
Use it

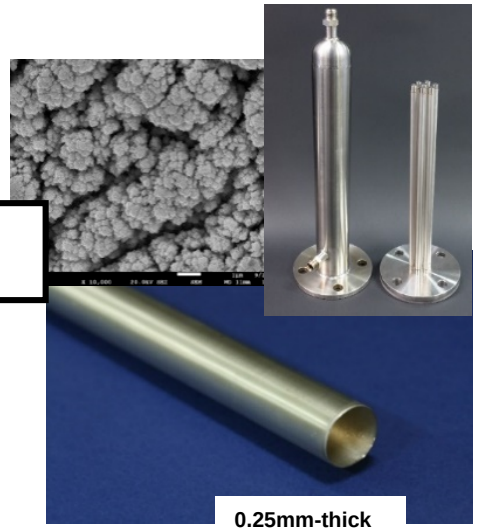
Catalytic Membrane reactor

Single stage production and separation of 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.







V in substrate: USD 180 m^{-2}
Catalytic layers: USD 100 m^{-2}
plus manufacturing costs

Pilot Ammonia ‘cracking’ facility

Gen 1 system:

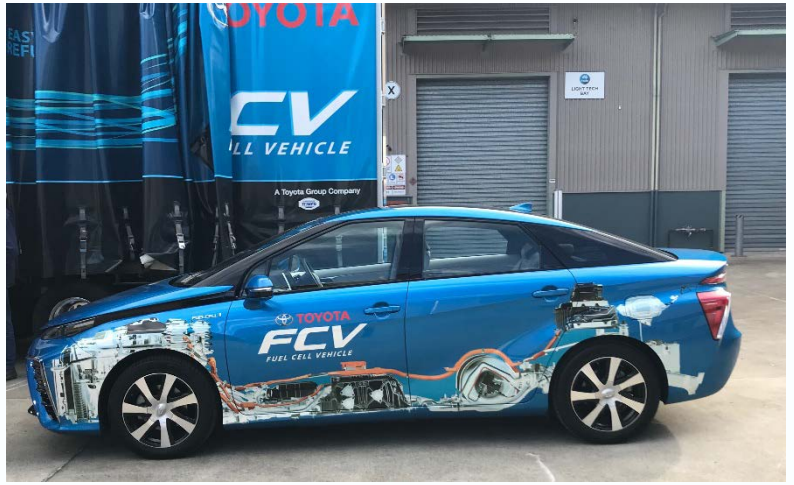
- SIEF funding
- Membrane area 0.3 m^2 (19 x 50 cm tubes ≈ 15 kg/day at 80% yield)
- 2-3 cars/day
- Located at CSIRO Brisbane, commissioned 2018

Gen2 plant:

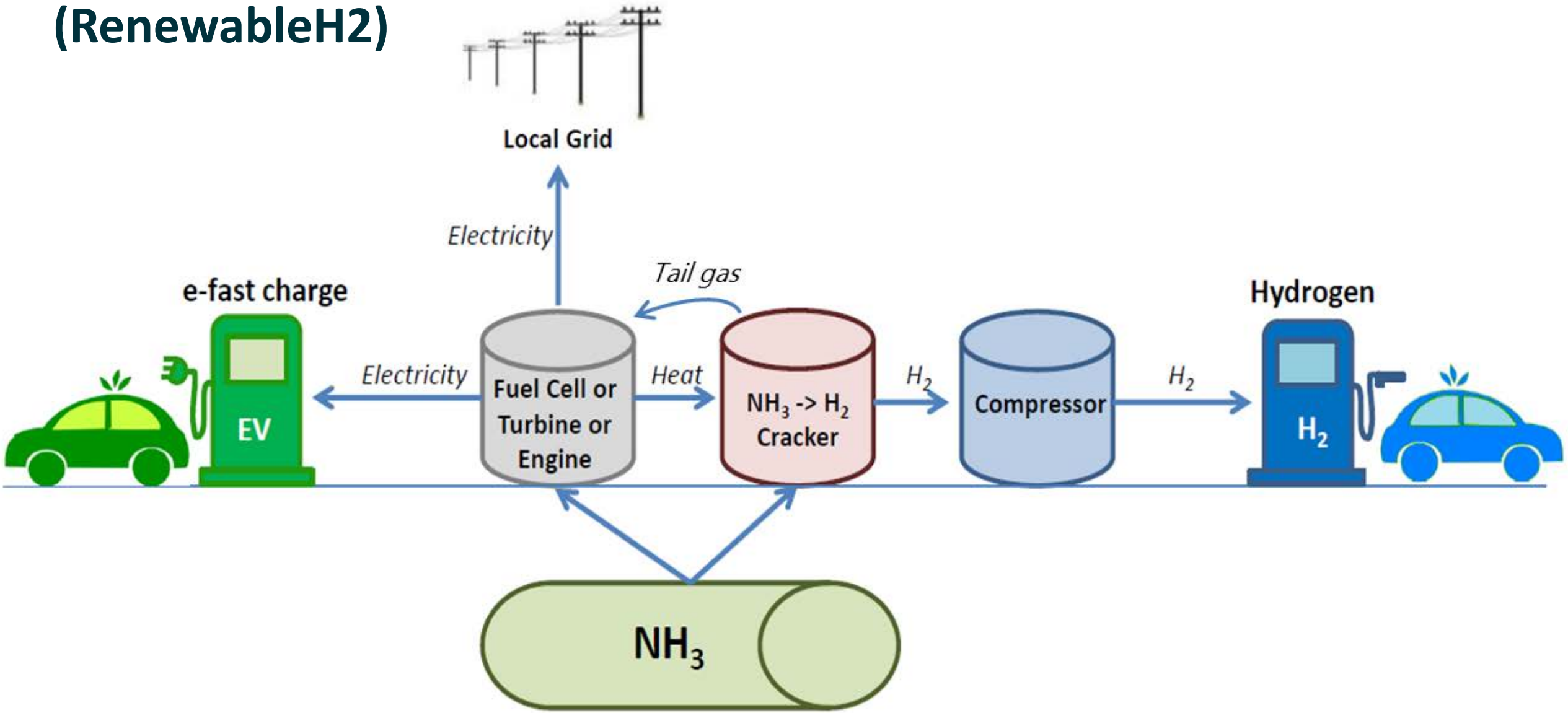
- 3 m^2 of membrane area (100 m)
- 150 -200kg/day
- Development and demonstration facilities supporting commercial development

Fuel cell vehicle refuelling with ammonia derived hydrogen

8 August 2018



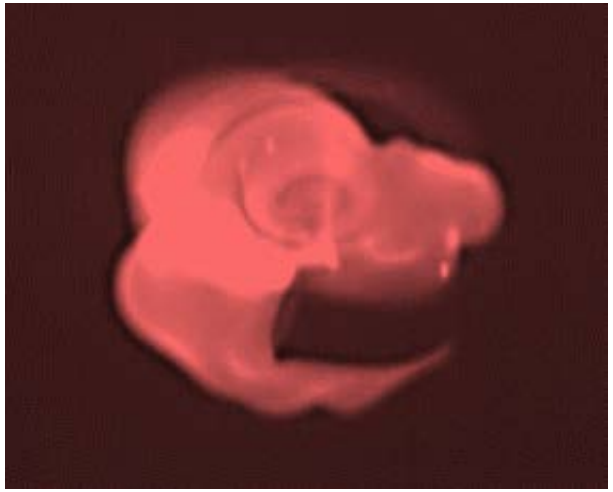
DEHPRA (RenewableH2)



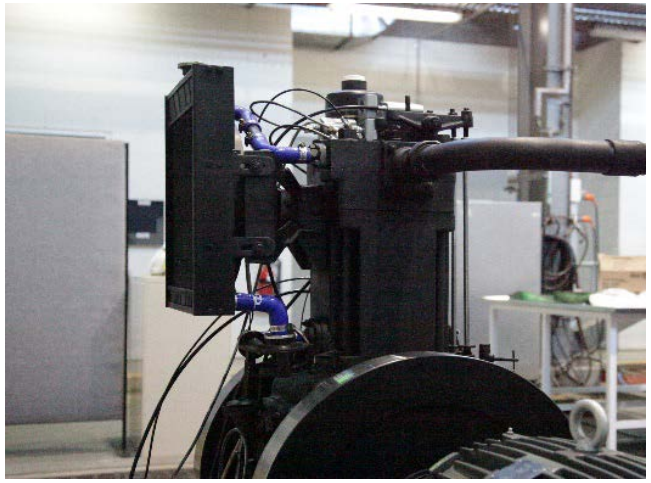
Source: Renewable Hydrogen Pty Ltd
Innovation patent: 2016101350

Ammonia as an engine fuel

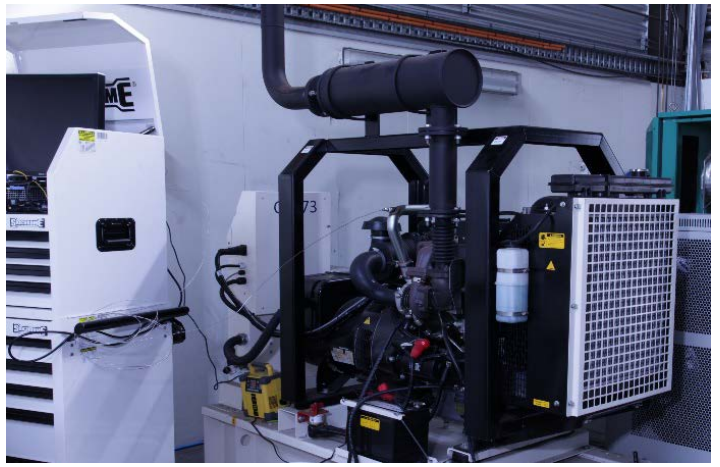
Ignition and combustion R&D



200 bar, 9 litre spray chamber, ignition and combustion rig



18kW, 4 litre, single cylinder (200-850 rpm)

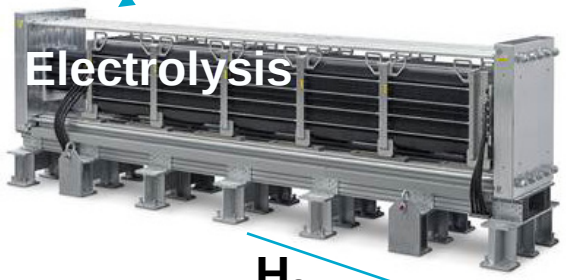


65kW, 3.3 litre, 3 cylinder (900-2200 rpm)

67kW GT (96000 rpm)

Hydrogen energy systems

Integrating and leveraging across industry sectors



H_2

N_2

NH_3

Power generation: Combustion (internal combustion engine or turbine)

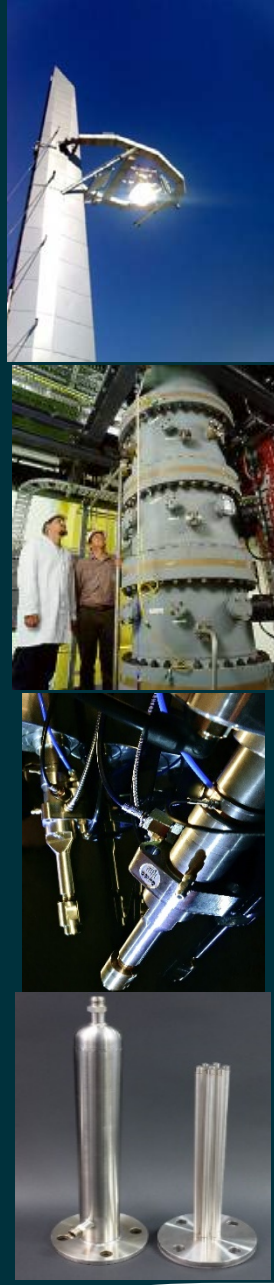
Power generation: Direct conversion (High-temperature fuel cell)

H_2 production: Decomposition and H_2 purification (FCEV etc)

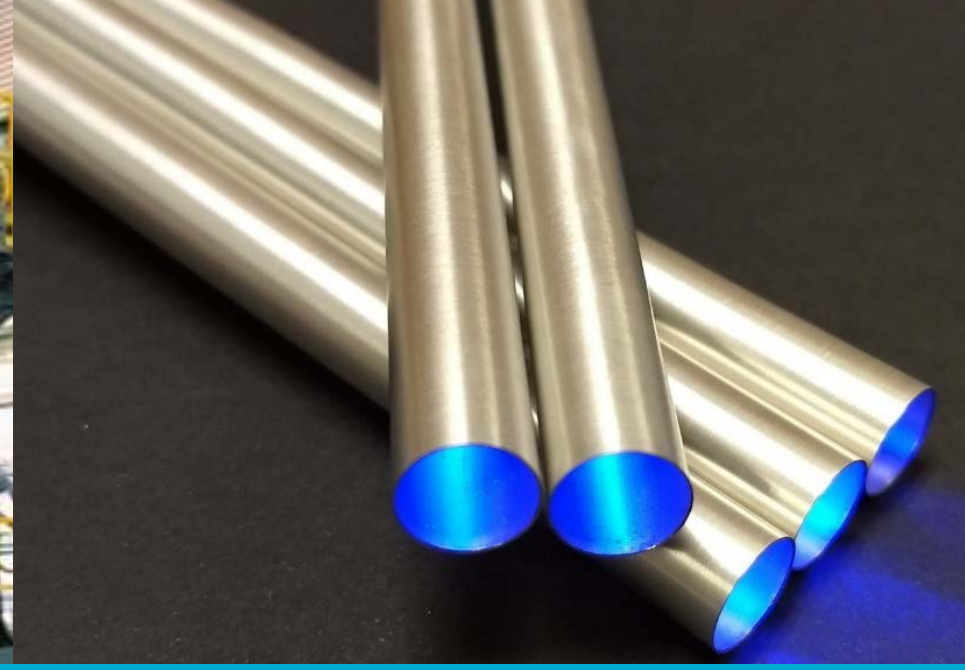
Hybrid H_2 and power systems – adaptive power and storage

Progressing Low Emissions Energy

- Need all energy options to create a sustainable and affordable energy portfolio
- Driving and coordinating Australia's role in development and deployment of low emissions and renewable energy technologies and systems globally
- **Creating a whole new industry around hydrogen energy systems and exportable renewables via ammonia and other suitable carriers**
  - Ammonia industry opportunity to integrate renewable hydrogen at scale
- **The Hydrogen Energy space is broad, and not limited to a single industry sector**
  - Distributed energy commodity in power, transport, industry, and agriculture needs new technologies and value chains
  - Real opportunities for emissions reduction, sector coupling, and new industry development
- National and International partnerships are needed to facilitate research, development, demonstration and deployment







Further Information:

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