Hydrogen Energy Value Chains:
Ammonia as an enabling hydrogen carrier

David Harris
Research Director: Low Emissions Technologies

CSIRO ENERGY
www.csiro.au
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\textsubscript{2} capture

- Emissions characterisation, reactions & impacts
- CO\textsubscript{2} capture technologies for current and next generation energy systems
  - Post combustion capture (PCC), membrane systems (CO\textsubscript{2}/H\textsubscript{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, electrolyzers, 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
H₂ 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 H₂ 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 H₂ energy systems

- Reducing cost of electrolysis
- Gasification routes for coal, biomass & wastes to hydrogen
- Scalable, intermittency-friendly NH₃ production
- Decarbonisation of heavy transport and distributed power
- New renewable energy export industry
- Other carriers: methanol, SNG...
- Ammonia cracking for decarbonisation of vehicle transport systems
Concentrated Solar Thermal technologies
Integration of solar energy in thermal and chemical processes

- Solar Steam
- SolarGas
- Solar HTF

Heliostat and Receiver Technologies

- Steam turbine
- Shift Reactor
- Gas turbine – simple or combined cycle
- Supercritical CO₂
- sCO₂ Brayton Cycle

- Industrial process heat
- Electricity
- Hydrogen production
- Liquid transport fuels via Fischer Tropsch or Methanol

SMR & WGS processes
- Solar syngas and H₂
- 25% solar energy embodied
- Pilot scale demonstrated to 600kW th
Gasification: a flexible enabling technology

Source: Shell 2007
KHI “CO₂ free hydrogen chain”
Gasification of Australian brown coal with CCS

Hydrogen capacity: ~770 tonne/day

Make it  Move it  Use it
CO$_2$-neutral hydrogen carriers

![Graph showing volumetric and gravimetric densities of different hydrogen carriers including Ammonia, Methanol (pre-reforming), Methane, MCH, LH$_2$, 700 bar H$_2$, and 200 bar H$_2$.](image-url)
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
A route to solar powered nitrogenase
Harnessing biological pathways for ammonia production

**In vivo**
ferredoxin

**In vitro assays**
dithionite

**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 H₂ from ammonia-derived mixed gas streams
- This concept can also be applied to NG reforming, CO shift, or any process with H₂ as a product.

**Feed stream (high pressure)**
- N₂, NH₃, H₂

**Feed-side surface**
- High catalytic activity to H₂ dissociation
- Tolerance to non-H₂ species
- Low transport resistance
- High thermal stability
- Low cost

**Core**
- High permeability
- Embrittlement resistance
- Low cost

**Permeate side surface**
- High catalytic activity to H₂ recombination
- Low transport resistance
- High thermal stability
- Low cost

**Pure hydrogen (low pressure)**

Catalytic alloy layer (200 nm)
- V in substrate: USD 180 m⁻²
- Catalytic layers: USD 100 m⁻² plus manufacturing costs

0.25mm-thick dense metal tube
Pilot Ammonia ‘cracking’ facility

Gen 1 system:
- SIEF funding
- Membrane area 0.3 m² (19 x 50 cm tubes ≈ 15 kg/day at 80% yield)
- 2-3 cars/day
- Located at CSIRO Brisbane, commissioned 2018

Gen2 plant:
- 3 m² 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

- Solar PV
- Wind
- Electrolysis
- Air separation

**Power generation:** Combustion (internal combustion engine or turbine)

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

**H₂ production:** Decomposition and H₂ purification (FCEV etc)

**Hybrid H₂ and power systems – adaptive power and storage**

- H₂
- N₂
- NH₃ synthesis

NH₃
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:

David Harris  
Research Director: Low Emissions Technologies  
CSIRO Energy  
david.harris@csiro.au