

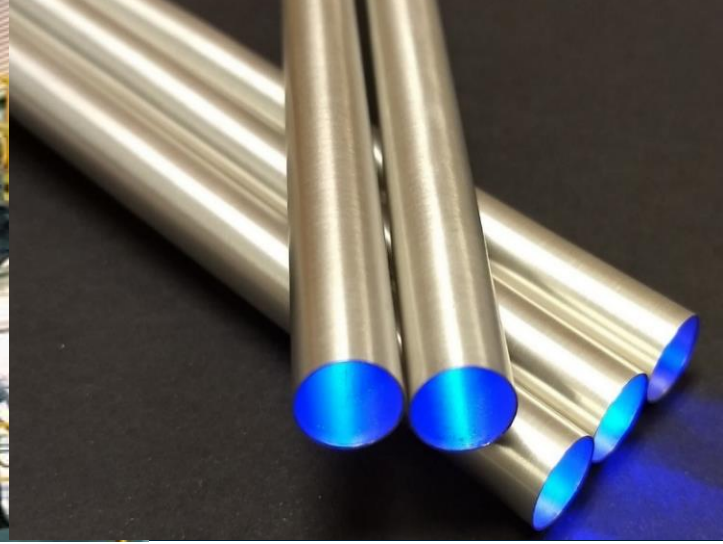

Ammonia as an energy carrier

Leveraging technologies and infrastructure to decarbonise global energy systems

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CSIRO Energy
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Background

- Need all energy options to create a sustainable and affordable energy portfolio
- 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, export
  - Challenges of scale
  - **Ammonia's role as an energy bridge**
- Collaboration and Partnership
  - Leveraging capability of research, industry and government
  - Facilitating commercial scale development and deployment

The Hydrogen Value Chain

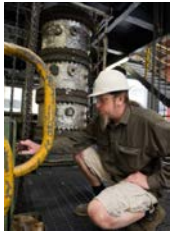
Make it → **Move it** → **Use it**

Ammonia as a hydrogen carrier

Building on existing industries and infrastructure

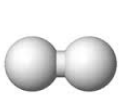
Reducing cost of electrolysis

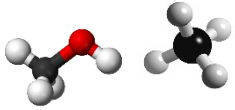
Solar thermal



Gasification routes for coal, biomass & wastes to hydrogen

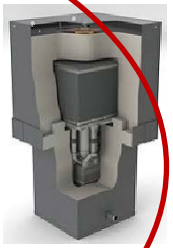
Scalable NH_3 production



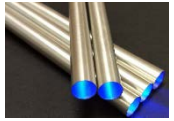


Other carriers: methanol, SNG…

New renewable energy export industry



Decarbonisation of heavy transport and distributed power
Engines, fuel cells, turbines..

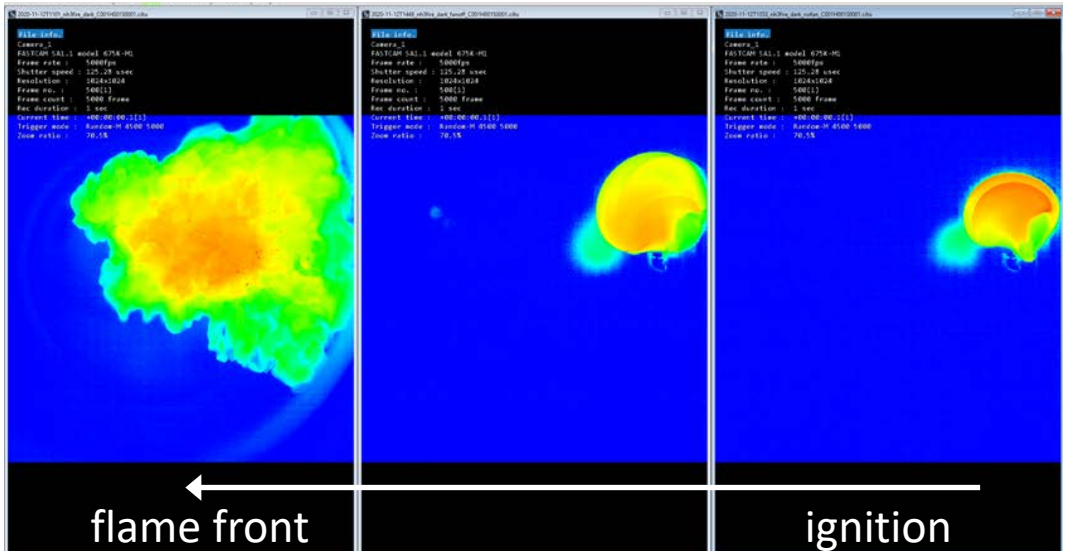


H_2

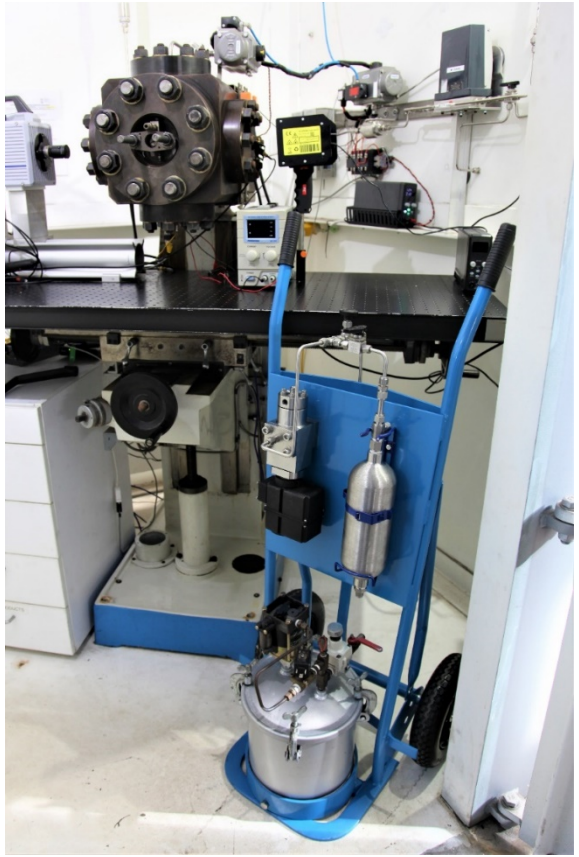
Ammonia cracking for decarbonisation of vehicle transport systems

Combustion fundamentals:
Ignition and spray combustion chamber

- homogeneous or spray combustion testing
- ongoing for LNH3 and mixtures at up to 200 bar

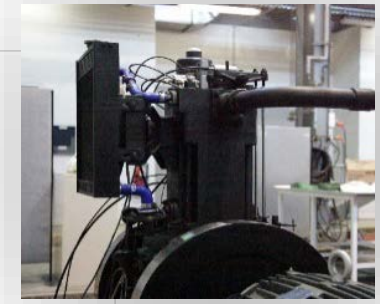


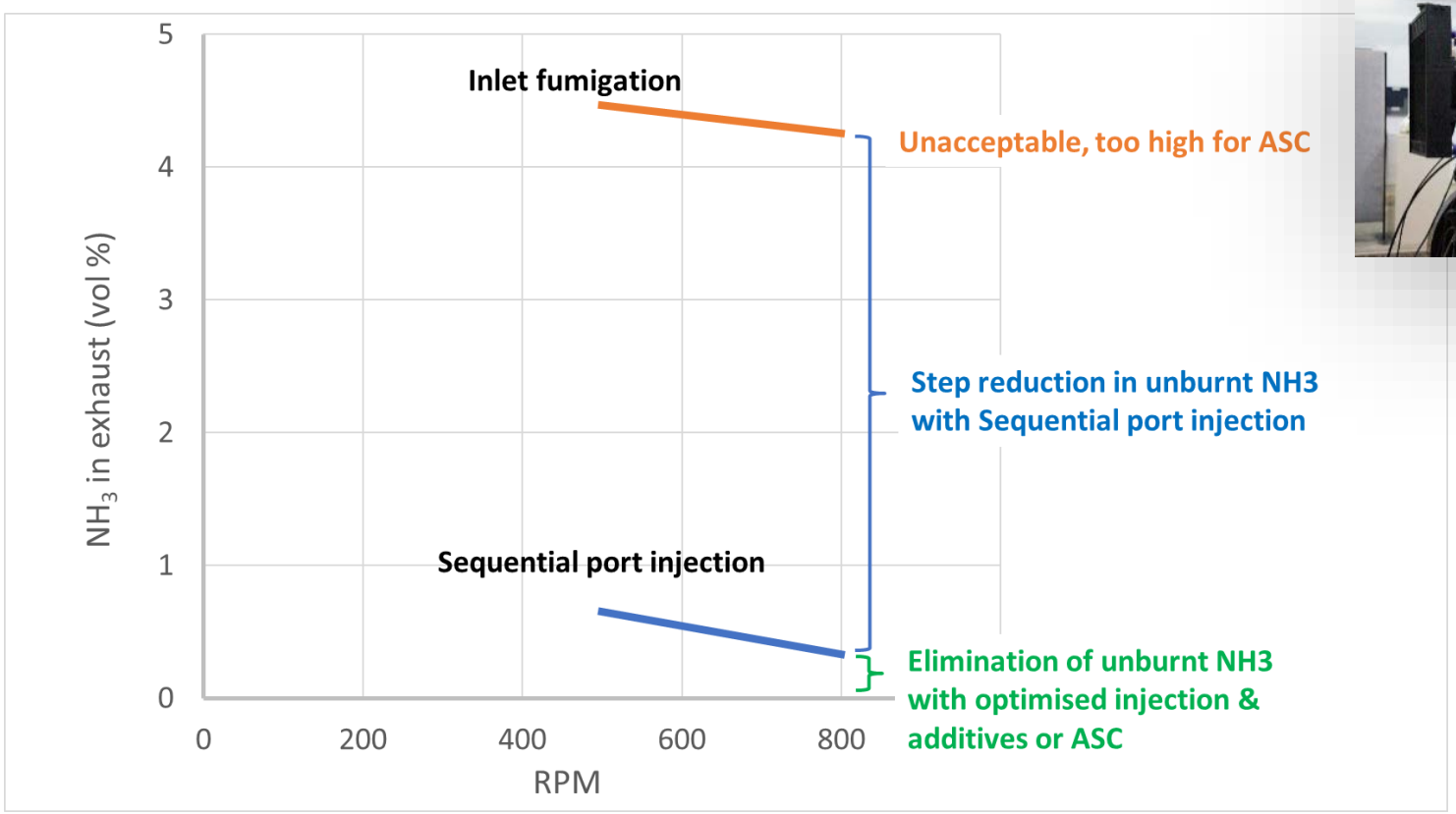
Homogeneous (premixed) combustion



spray combustion

Engine tests
step reduction in NH3 in exhaust with sequential port injection





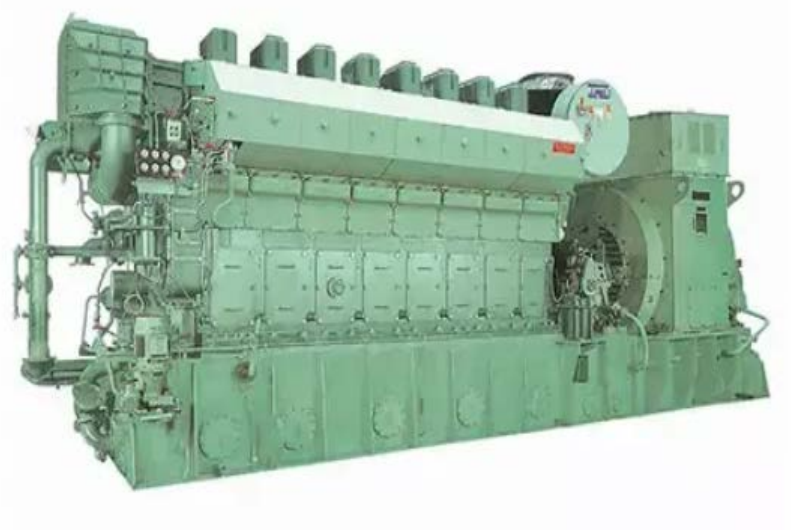
* ASC - ammonia slip catalyst *cf* EURO5 equipment

Prototype port injector

- Scalable design
- Capable of sequential port injection of engines up to 2,000 rpm
- Very short latency (<1ms) even with larger designs for increase shot capacity
- Matching high speed driver developed
- Excellent repeatability and reliability
- Can be used for either LNH3 or high pressure gaseous NH3

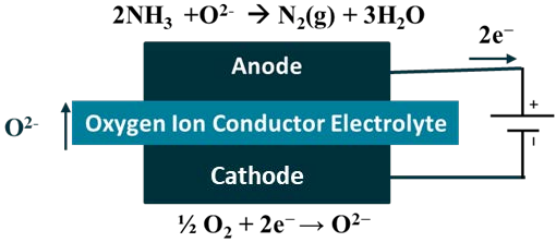
Large engine trials

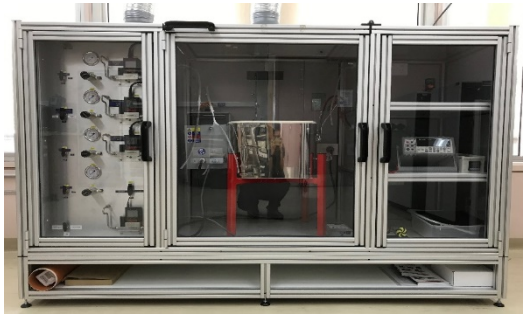
- 2 types of injection system have been designed for a 4-stroke, 500rpm engine
- Discussions with 2 Australian consortia with respect to full scale demonstrations
  - Opportunities:
    - the ability for near commercial scale trials at small scale
    - the availability of low cost, large bore, low speed 4-stroke engines as MW scale gensets
    - discussions with engine manufacturer



Ammonia solid oxide fuel cell (SOFC)

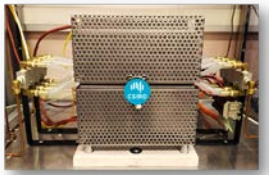
- Direct utilisation of ammonia in solid oxide fuel cell can produce combined heat and power efficiency of over 80%.
- Solid state device based on oxygen ion conductors:
  - ammonia decomposed to produce electricity in a single reactor without external ‘cracking’
  - Temperature range of 500 to 800°C
  - CSIRO is developing new electrode chemistries and cell designs to improve efficiency and durability.





Cell/stack test rig (10 kW scale)

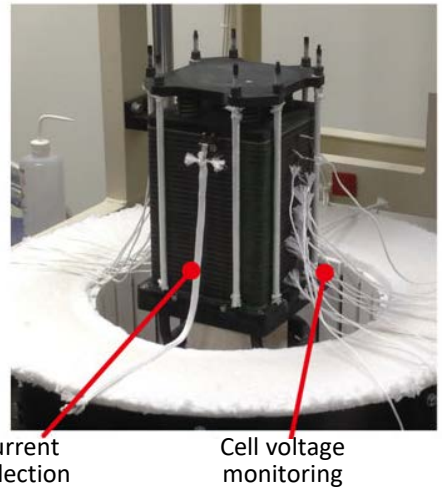
Tube Cells



0.25 kW Stack

Ammonia solid oxide fuel cell:
strong international RD&D focus

- There is a significant interest in this technology in Japan and Korea.
- Materials and cells used for SOFC operated with NG are being trialled for ammonia.
- Focus is on improving the fuel utilisation and electric efficiency of the stack.
- Kyoto University have demonstrated a 1kW SOFC sourced from Noritake Co. using ammonia.
- The stack produced ~ 700W power and was operated for 1000h at fuel utilisation of around 80%.

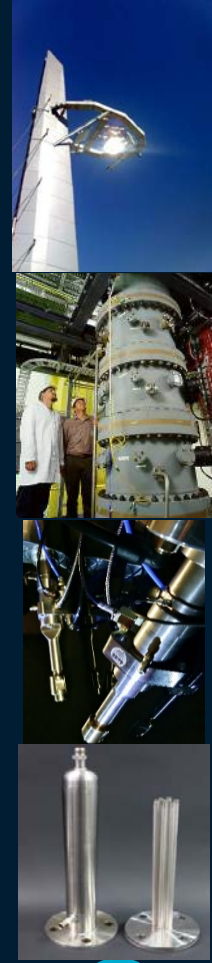


A 30-cell direct ammonia SOFC*

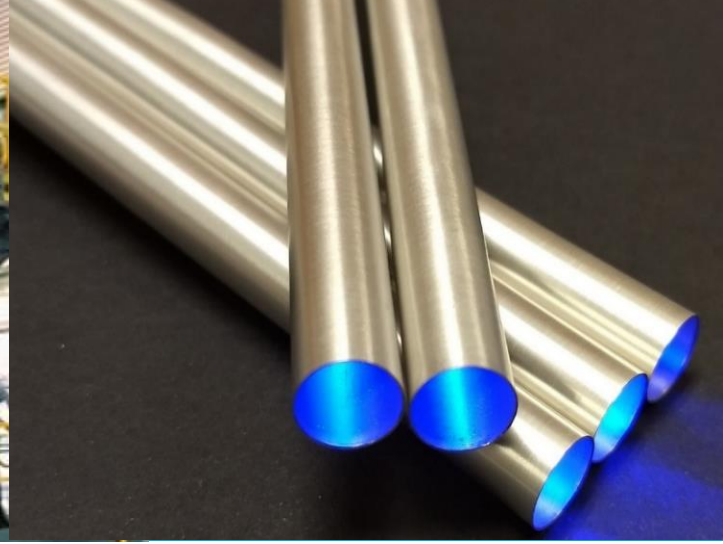
**Development of 1kW-class ammonia fuelled solid oxide fuel cell stack, Kishimoto et al. Fuel Cells 20, 2020, 1: 80-88*

Progressing the renewable hydrogen opportunity

- **Creating a whole new industry around hydrogen energy systems and exportable renewables via ammonia and other suitable carriers**
  - Opportunity for existing industries to integrate renewable hydrogen at scale
- **Ammonia is an attractive hydrogen carrier and the infrastructure for manufacturing, storage, transport and safety already exists**
  - technologies and initiatives to produce and utilise *renewable* ammonia at scale are needed.
- **The Hydrogen Energy space is broad, and not limited to a single industry sector**
  - Distributed energy carrier in power, transport, industry, and agriculture needs new technologies and value chains
- Strong partnerships are needed to facilitate research, development, **demonstration and deployment**
  - Industrial scale demonstrations are needed to leverage potential of ammonia as a renewable energy carrier







Thank you

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