NEWCASTLE INSTITUTE FOR ENERGY AND RESOURCES

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Ammonia Energy Association Presentation

# AMMONIAC: A Chemical Looping-Based Process for Production of Green Ammonia

Laureate Professor Behdad Moghtaderi

Priority Research Centre for Frontier Energy Technologies & Utilisation

AMMONIA ENERGY ASSOCIATION

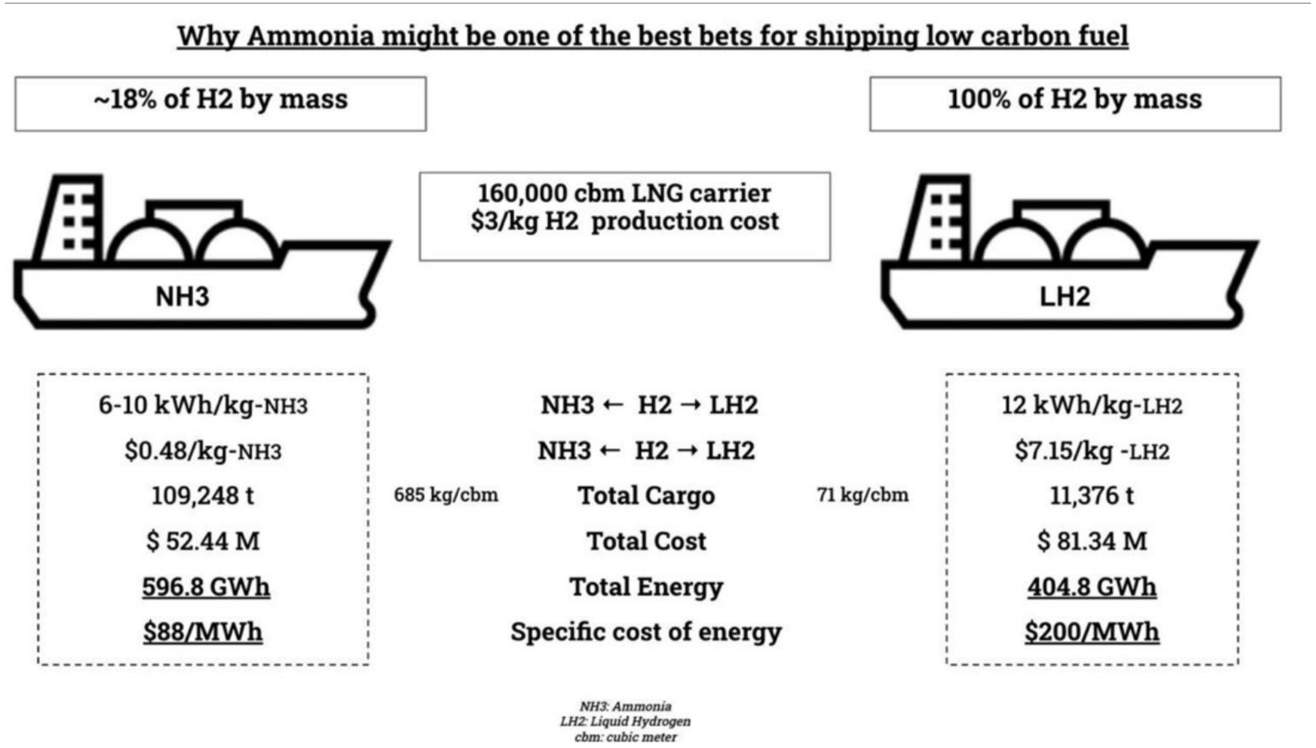
# Prof Moghtaderi's Group (Centre for Energy)

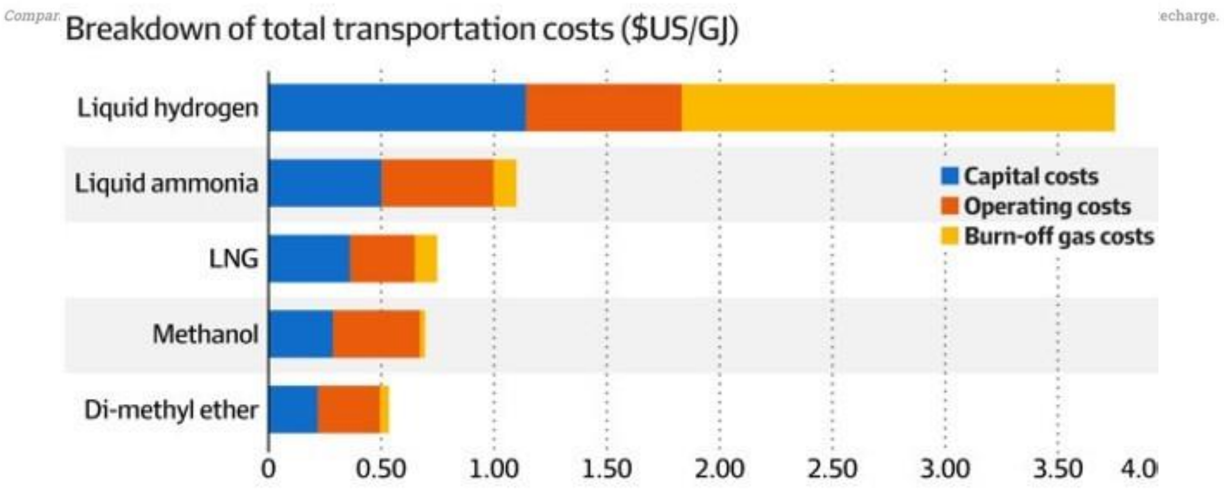
- Staff & Students
  - 20 Postdoctoral Research Fellows
  - 4 Technical & General support staff
  - 14 PhD Students
- Extensive array of laboratories and facilities worth $22 M
- Grants Income: ≈ $8 M/y
- Publications since 2017: 185
- RHD completions since 2013: 18

# Background

## Liquid Hydrogen VS Liquid Ammonia

| Characteristics and/or Properties | Liquid Hydrogen | Liquid Ammonia | Comment |
|---|---|---|---|
| Energy Content | 9.9 MJ/Liter | 15.3 MJ/Liter | An ammonia based system would be more compact and lighter |
| Boiling Point (@ 1 bar) | 20K (-253 C) | 240K (-33 C) | Given that any storage system will inevitably have some air with a boiling point of 79K, in the case of liquid hydrogen this air freezes to a solid with hazardous consequences. |
| Laten Heat of Vaporisation (@ 1 bar) | 6.3 ($kJ/m^3$) or 447 (kJ/kg) | 2 ($kJ/m^3$) or 1371 (kJ/kg) | The latent heat of liquid hydrogen in $kJ/m^3$ is about three times bigger than that of Ammonia. Thus, for the same heat influx, the evaporation rate of liquid ammonia would be three times faster in terms of the volume of evaporated liquid. |
| Viscosity | 13.06 (kg/m.s x $10^6$) | 157.9 (kg/m.s x $10^6$) | The low viscosity of liquid hydrogen may lead to sloshing during transportation giving rise to vapour explosion if the sloshing liquid get in contact with the relatively warmer surfaces (e.g., roof of the storage tank). |
| Molecular Structure | Has Ortho and Para structures | | Hydrogen is essentially a mixture of ortho- and parahydrogen. When liquefied at 20K, there is a slow but continuous transformation of the ortho-hydrogen to the lower energy parahydrogen in the form of boil-off which is undesirable. In addition, the co-existence of ortho- and para- rich liquid with different densities may lead to stratification and subsequent rollover with uncontrolled boiloff. |

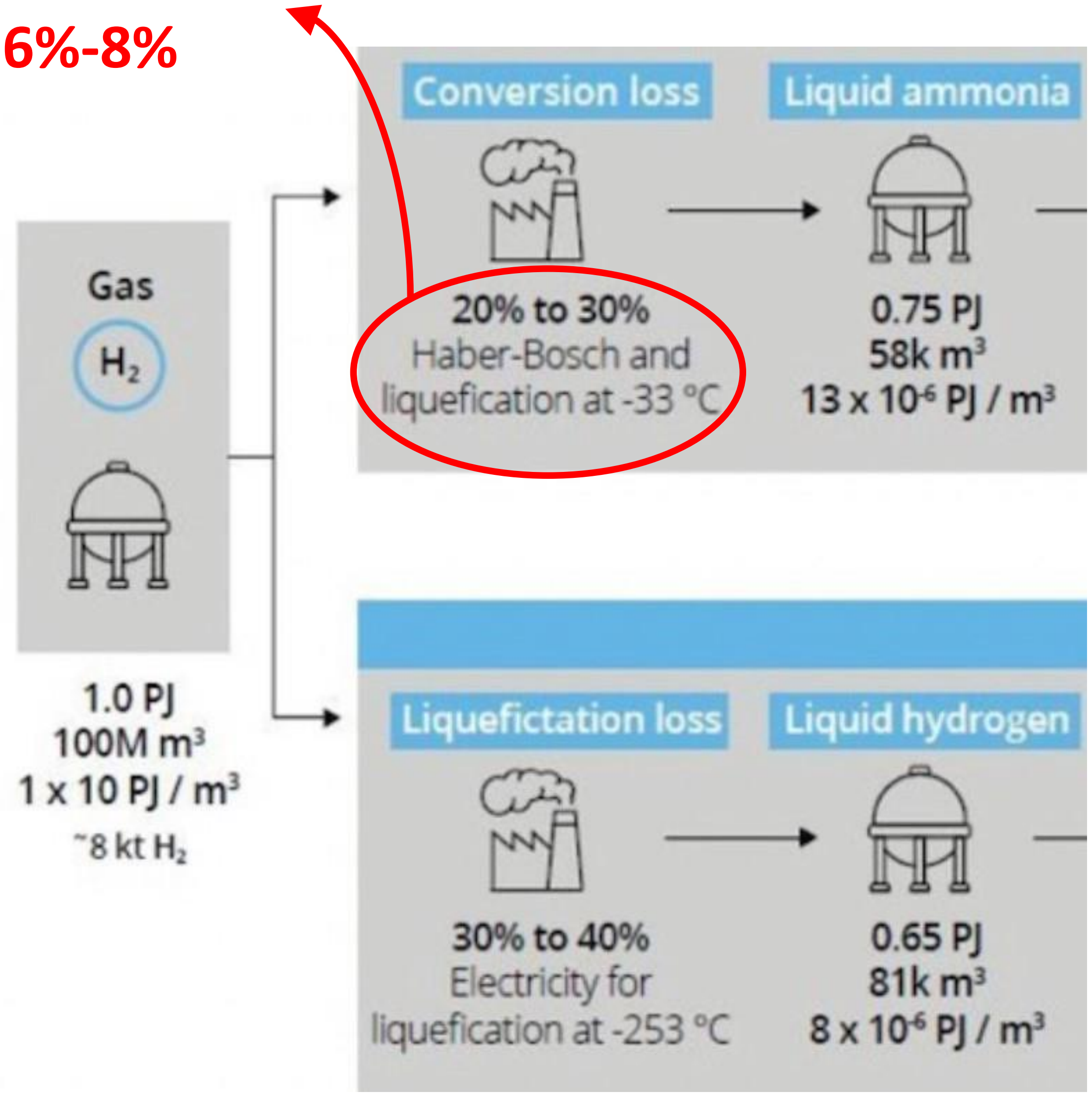




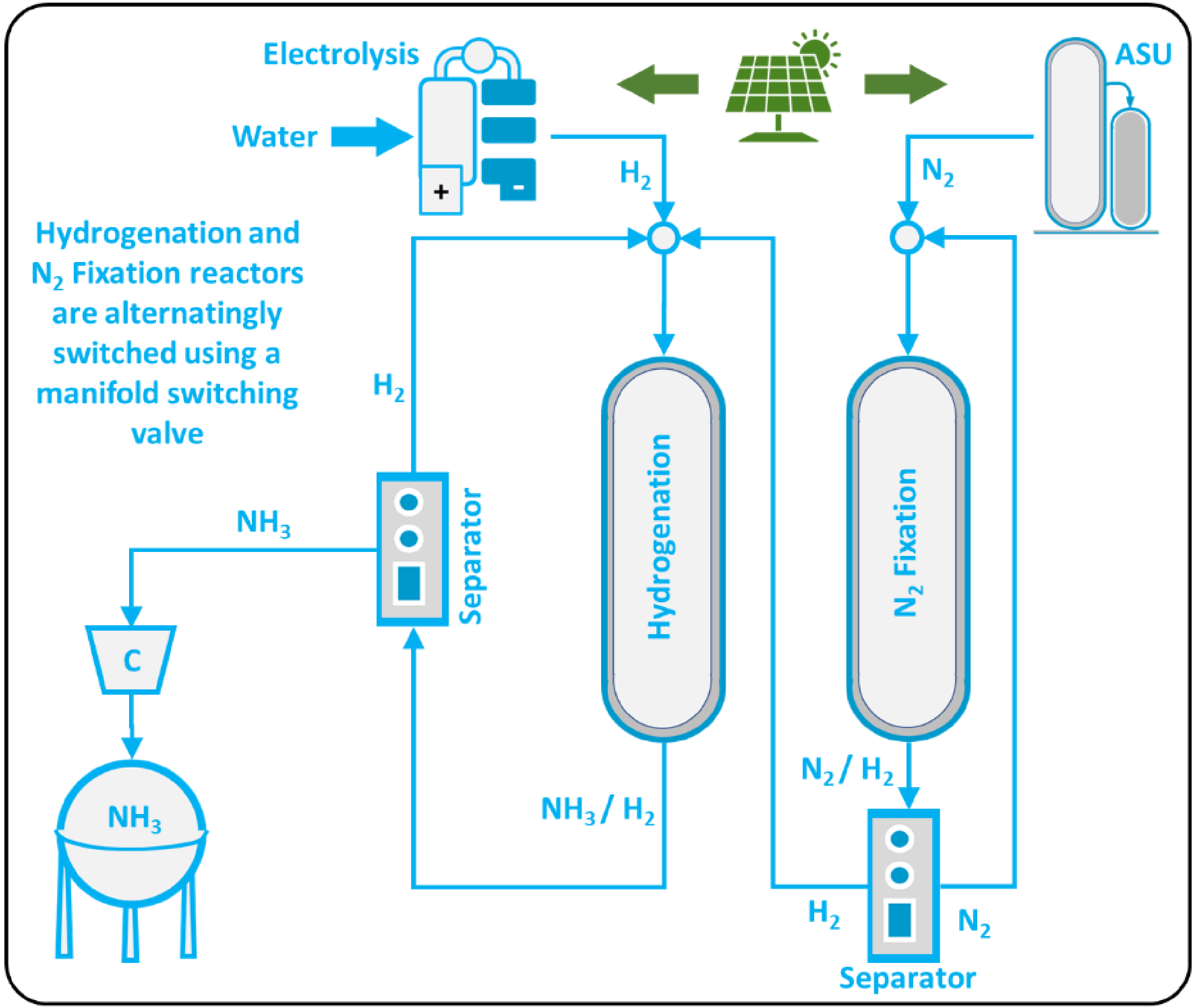

The Suiso Frontier left Hastings (Vic) in Jan 2022 after loading its cargo of liquid hydrogen.

**AMMONIAC**
**6%-8%**




- Since 1913 the production of ammonia at industrial scale has been based on the Haber-Bosch process which is considered as one of the most important inventions of the 20th century.
- The Haber-Bosch process, $N2+3H2 \rightarrow 2NH3$, requires a catalyst to promote the reaction between nitrogen and hydrogen, and is only feasible at high temperatures (~430$^{o}$C) and pressures (~100 atm).
- The process has been extremely well optimised over the past 110 years.
- However, given that the primary source of hydrogen in the Haber-Bosch process is natural gas, the process is still responsible for approximately 1.1% of the global energy consumption and about 1% of global greenhouse gas (GHG) emissions.
- Typically, 1.9 tonnes of CO2 are released per tonne of ammonia produced when natural gas is utilised to produce hydrogen.

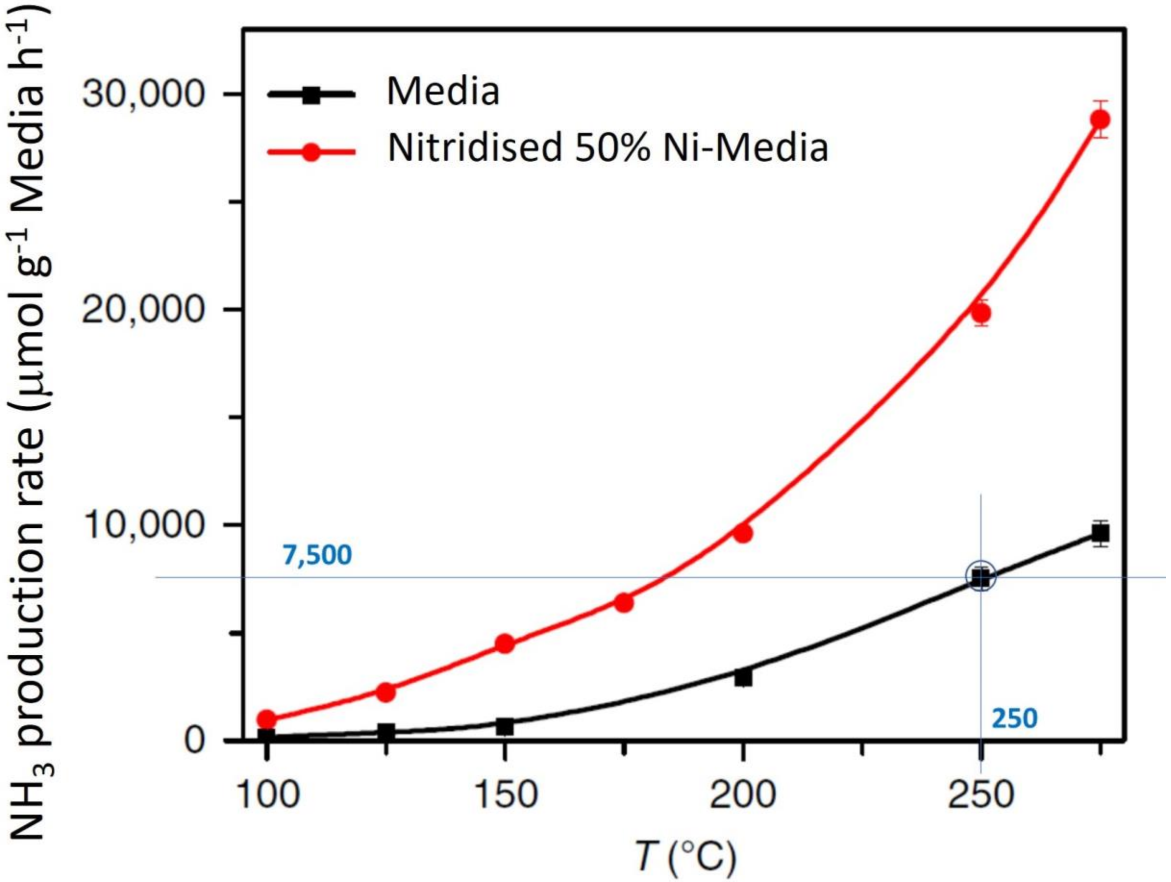
# AMMONIAC Process




- The AMMONIAC process is a thermochemical looping process for production of green ammonia from renewable hydrogen and atmospheric nitrogen.
- The process essentially “breathes in” nitrogen and “breathes out” ammonia by simply cycling between different reaction environments at ambient pressure.
- This breakthrough process is a simple, cost effective and environmentally friendly alternative to the conventional Haber-Bosch process and other emerging technologies for ammonia synthesis.


Front
Back

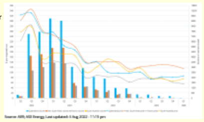
## TRL 4


Media
Nitridised 50% Ni-Media
30,000
20,000
10,000
0
7,500
250
100
150
200
250
T (°C)
NH3 production rate (μmol g-1 Media h-1)

Scenario 1: The Required Electricity Is Purchased from Renewable Energy Providers

**In this case:**

Avg Cost of Electricity = 144.00 $/MWh NSW (2022 and beyond)



**Total Cost =** $5,561,530 per year

**Therefore:**

Inflation Rate = 5 %
CRF = 0.065
Ccap = $11,916,736
CO&M = $273,250
CEnergy = $5,561,530
MNH3 = 3650000

**LCOA =** **Using Ammoniac Process** **$1.811 per kg**
**$1,811 per tonne**

Procurement Resource — Insights That Matter!

1.61 USD to A$
0.22 RMB to A$
0.08 MXN to A$

| Comparison with Fossil Fuel Based Ammonia in Different Markets | Wholesale Price at Major Global Markets ($/t) | | | | |
|---|---|---|---|---|---|
| | Asia / Oceania | Europe | North America | Latin America | |
| **Fossil-Fuel Based Ammonia** | 1100 | 2616 | 2294 | 1192 | 2022 Data |
| **AMMONIAC Based Ammonia (Green)** | 1811 | 1811 | 1811 | 1811 | |
| **Difference** | -711 | 805 | 483 | -619 | |
| **AMMONIAC Viability** | Not Viable | Viable | Viable | Not Viable | |

Scenario 2: The Required Electricity Is Produced at the Plant Using a Dedicated Solar Farm

**In this case:**

Avg Cost of Electricity = 0.00 $/MWh

**Total Cost =** $0 per year

**However the capital cost of the solar farm must be added tp Ccap**

The indicative unit cost of a typical solar PV farm = 1390 $/kW Based on Tony William's advice
**Total Cost of the solar farm =** $6,128,335

**Therefore:**

Inflation Rate = 5 %
CRF = 0.065
Ccap = $18,045,071
CO&M = [illegible]
CEnergy = $0
MNH3 = 3650000

**LCOA =** **Using Ammoniac Process** **$0.464 per kg**
**$464 per tonne**

| Comparison with Fossil Fuel Based Ammonia in Different Markets | Wholesale Price at Major Global Markets ($/t) | | | |
|---|---|---|---|---|
| | Asia / Oceania | Europe | North America | Latin America |
| **Fossil-Fuel Based Ammonia** | 1100 | 2616 | 2294 | 1192 |
| **AMMONIAC Based Ammonia (Green)** | 464 | 464 | 464 | 464 |
| **Difference** | 636 | 2153 | 1831 | 728 |
| **AMMONIAC Viability** | Viable | Viable | Viable | Viable |


LCOA = Using Ammoniac Process $0.464 per kg
$464 per tonne

| Comparison with Fossil Fuel Based Ammonia in Different Markets | Wholesale Price at Major Global Markets ($/t) | | | |
|---|---|---|---|---|
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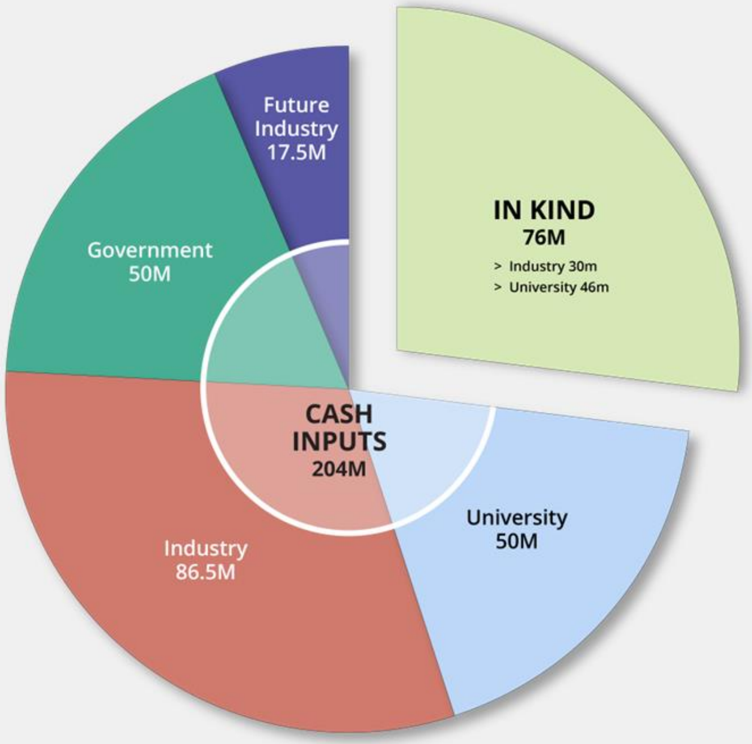
| Fossil-Fuel Based Ammonia | 1100 | 2616 | 2294 | 1192 |
| AMMONIAC Based Ammonia (Green) | 464 | 464 | 464 | 464 |
| Difference | 636 | 2153 | 1831 | 728 |
| AMMONIAC Viability | Viable | Viable | Viable | Viable |

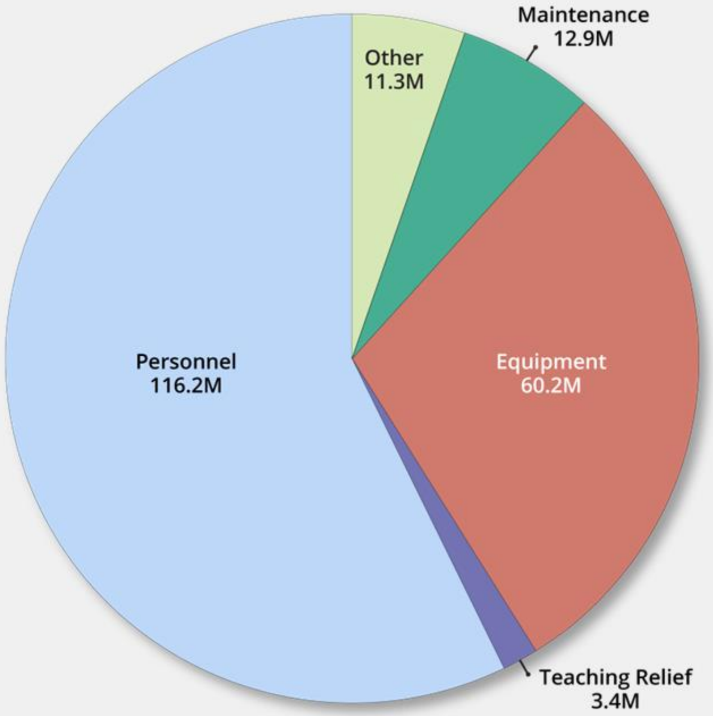
# AMMONIAC Project

Trailblazer
Recycling &
Clean Energy

# Leveraged government funding




**$280M program**
(government funding leveraged at 4.5 to 1)




**Cash expenditure**
$204M

## INPUTS → OUTPUTS (ACTIVITIES) → OUTCOMES → IMPACT

### INPUTS

- #1 in Australia for RaCE research
- World-class facilities
- Academic workforce
- Pipeline of IP & spinouts
- CSIRO, commercialisation accelerators & investors
- $96m university
- $115m industry

RESEARCH PUSH INNOVATION

**PUSH**

**PULL**

"INDUSTRY PULL INNOVATION

### OUTPUTS (ACTIVITIES)

**THEMES & PROJECTS**
- Next Gen Solar PV
- Electrification, Energy Systems & Storage
- Sustainable Fuels & Chemicals
- Recycling & MICROfactories™

**TRAILBLAZING INNOVATOR PROGRAM**
- Workplace Frameworks
- Innovation Rewards
- Technology Translation Squad
- SME Innovation Vouchers

**RESEARCH TRANSLATION ECOSYSTEM**
- Prototyping Workshops
- Translation Accelerator Unit
- Foundry
- Manufacturing Precincts
- Hunter Advanced Science & Technology Co-location

**CRITICAL SKILLS DELIVERY**
- Industry Fellowships
- Micro-credentials
- Research Training Centre
- Work-integrated Learning
- Embedded Learning Pathways

### OUTCOMES

- Accelerated commercialisation of research
- Mature collaboration frameworks
- Upskilled RaCE workforce

### IMPACT

- World-leading commercialisation
- Sovereign manufacturing capability
- Circular supply chains
- Globally competitive industries
- Economic boost $15 billion GDP
- Up to 180Mt emissions avoided
- Support 5,200 regional jobs

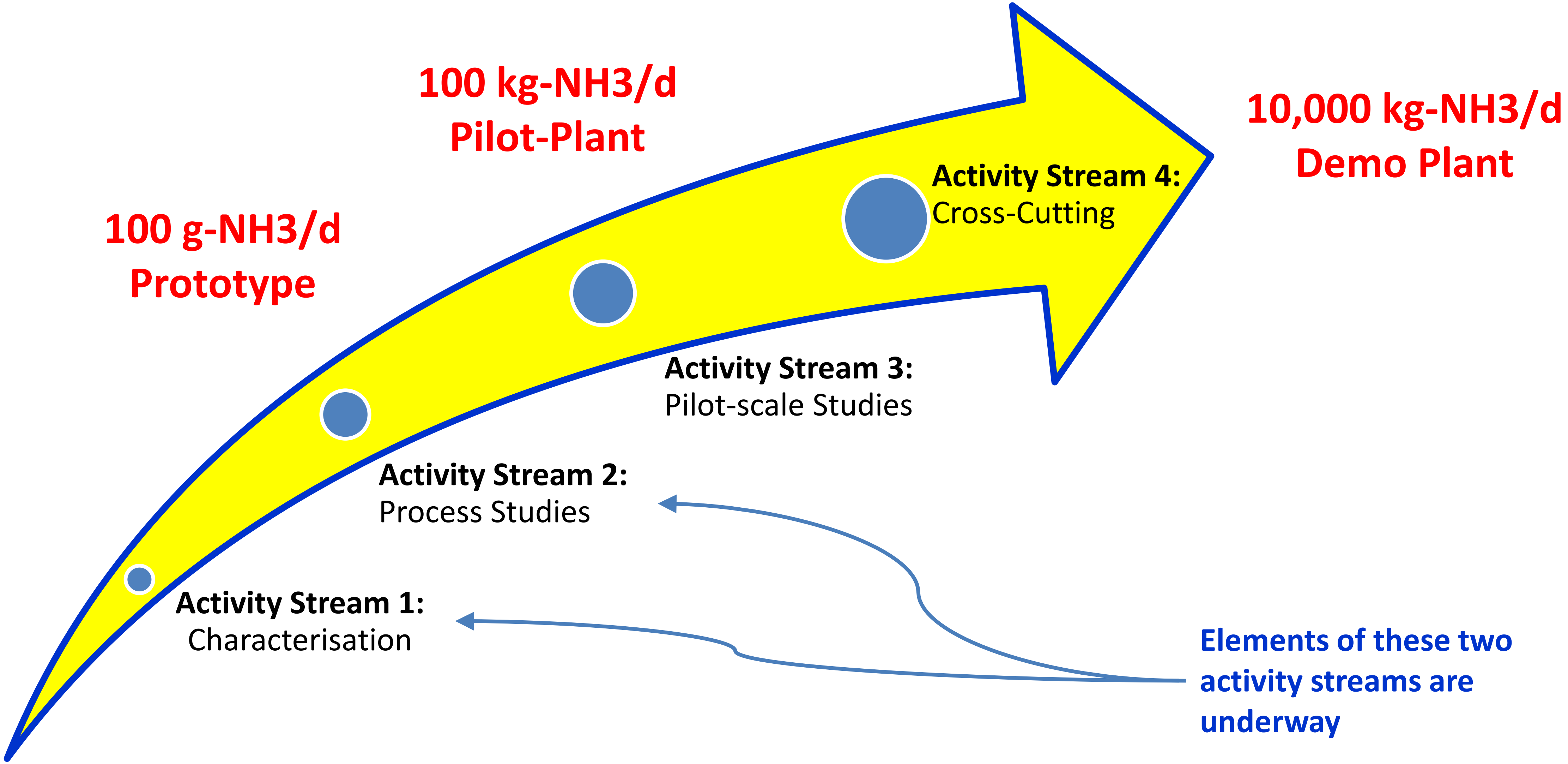
◄ A RUNNING START ► | ◄ INNOVATION PATHWAY: R&D TO DEPLOYMENT & SKILLS BUILDING ► | ◄ MEASURABLE OUTCOMES ►

# Theme 3: Sustainable Fuels and Chemicals Manufacturing

Theme Leader: Prof Behdad Moghtaderi

- AMMONIAC: A Chemical Looping-Based Process for Production of Green Ammonia (**Element 1 Pty Ltd**)
- Achieving Negative Emissions in Production of Green Steel and Green Chemicals Using the VAMCO Family of Gas Separation Technologies (**Ascon Energy Pty Ltd**)
- KIMIYA: A Technology Platform for Conversion of Organic Waste to Sustainable Chemicals and Fuels (**ELMNTRE Pty Ltd**)
- Development of a Novel, Low-Cost, High Performance, Safe and Sustainable Hydrogen Storage Material (**LAVO Hydrogen Storage Technology Pty Ltd**)
- Advanced Technology Hydrogen Compressor Development and Testing (**Siemens Energy Pty Ltd**)

## Project Has Commenced as of April 5, 2023



THANK YOU

# Questions

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