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# Performance Investigation on Electrochemical Compressor with Ammonia

## Paper 2380

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# Outline

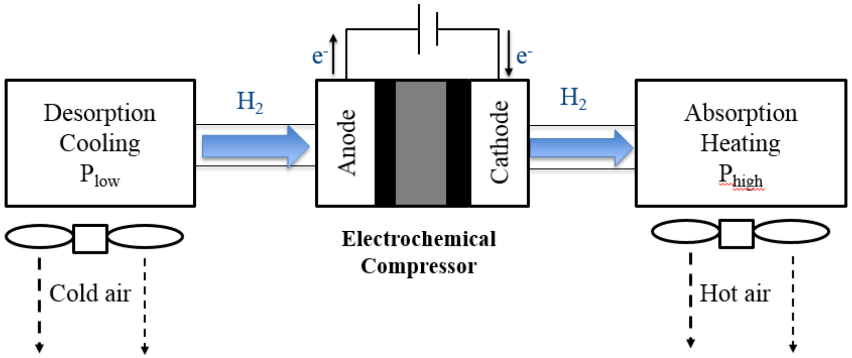
- Introduction
- Objectives
- Open Loop Experimental Results
- Closed Loop Experimental Results
- Limitations and Challenges
- Conclusions
- Future Work

# Introduction

- Current challenges in the refrigeration market
  - R-410A and R-134a have high GWPs
  - Considerable energy consumption for mechanical compressor on small cooling appliances
- Electrochemical compression system
  - Works with ammonia (environmentally friendly)
  - More energy efficient
  - Solid state with no moving parts, no lubrication oil, and no noise

# Previous Works

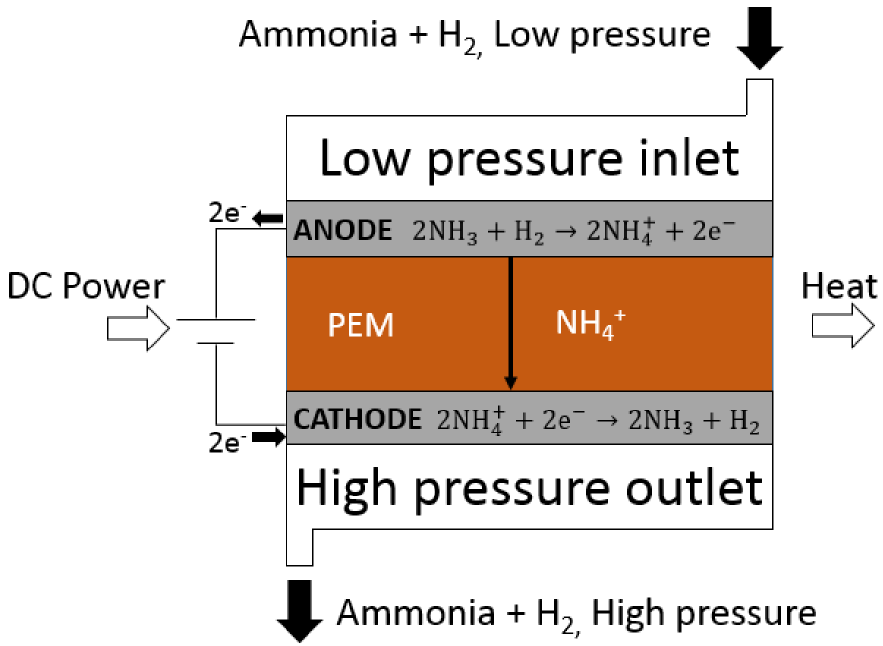
- Electrochemical hydrogen compressor
  - Hydrogen separation, storage and compression
  - Pressure of hydrogen can reach 130 bar
- Electrochemical compressor driven metal hydride heat pump
  - Controls pressure of hydrogen in two metal hydride reactors for adsorption and desorption
  - Potentially more energy efficient than mechanical compressor driven system





Tao et al., 2015. Electrochemical compressor driven metal hydride heat pump. Int. J. Refrigeration, 60:278-288
Grigoriev et al., 2010. Description and characterization of an electrochemical hydrogen compressor/concentrator based on solid polymer electrolyte technology. Int. J. Hydrogen Energy, 36: 4148-4155

# Electrochemical Ammonia Compressor (EC) Working Principle

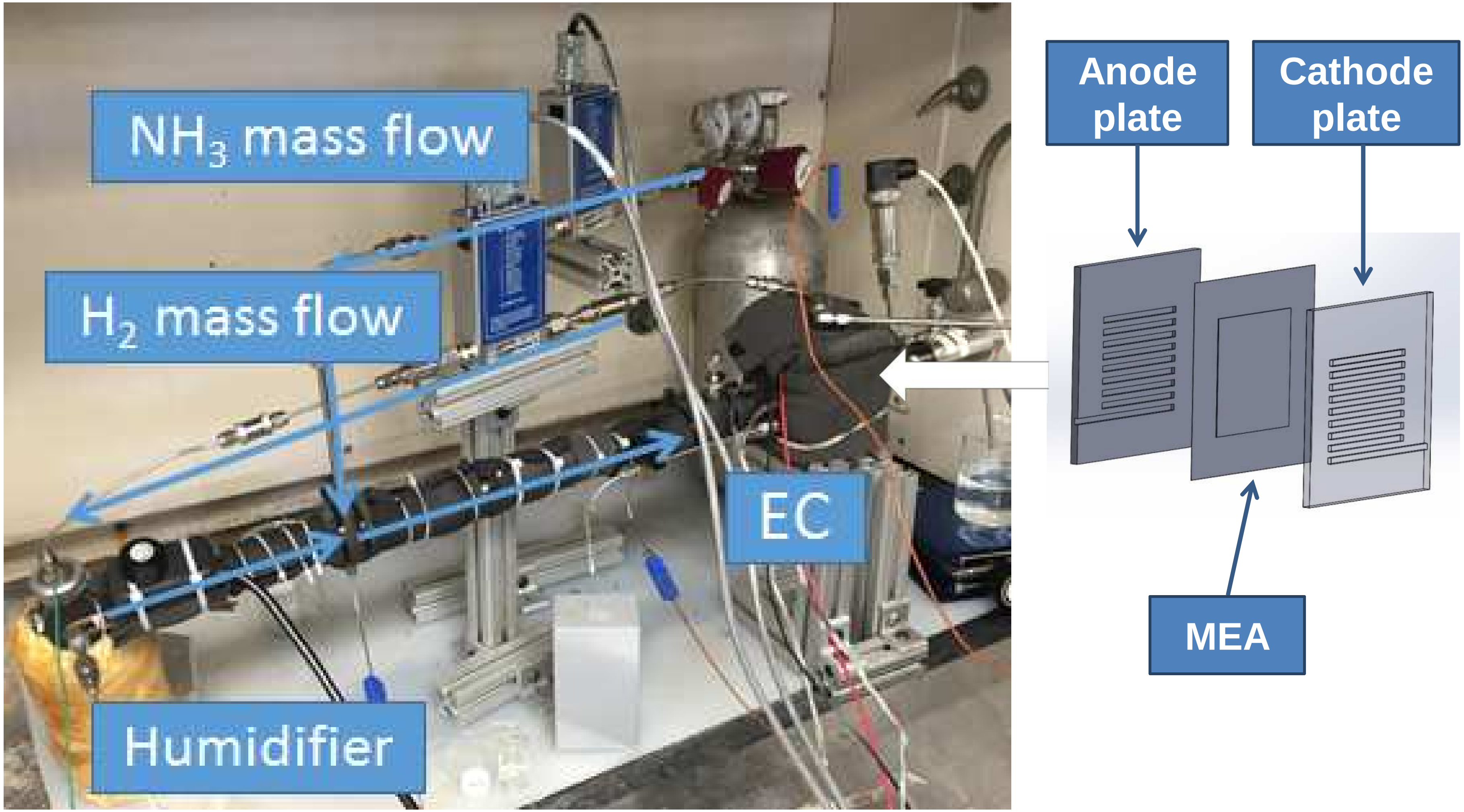



- Proton exchange membrane fuel cell design
- Under external electric field, ammonia and hydrogen react to form $NH_4^+$ and get transferred across the MEA, and regenerated at cathode
- Pressure increase based on increased gas molecules per volume
- The gas transfer ratio between ammonia and hydrogen is 2:1

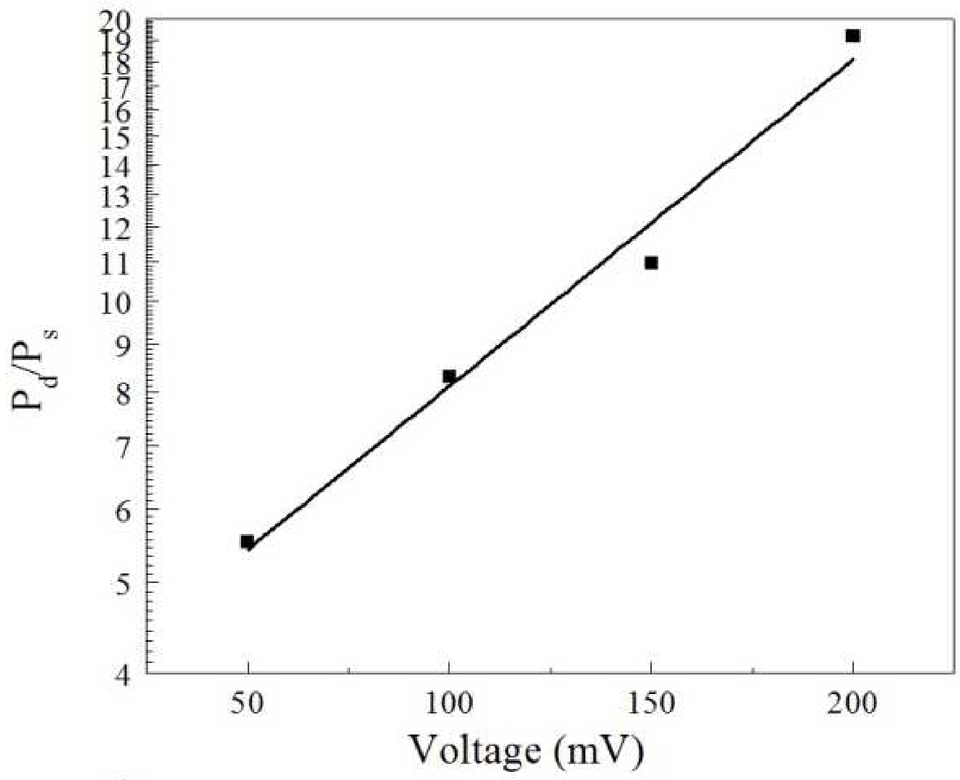
# Objectives

- Measure the EC performance at open loop
  - Relationship between voltage and compression ratio
  - Compare with theoretical Nernst equation
- Experimental study of EC at closed loop
  - Measure the voltage and current at constant refrigerant charge
  - Measure the pressure lift after the compressor
  - Measure the flow rate
- Investigate the feasibility of integrating EC into 200 W vapor compression cycle

# EC Prototype and Test Facility



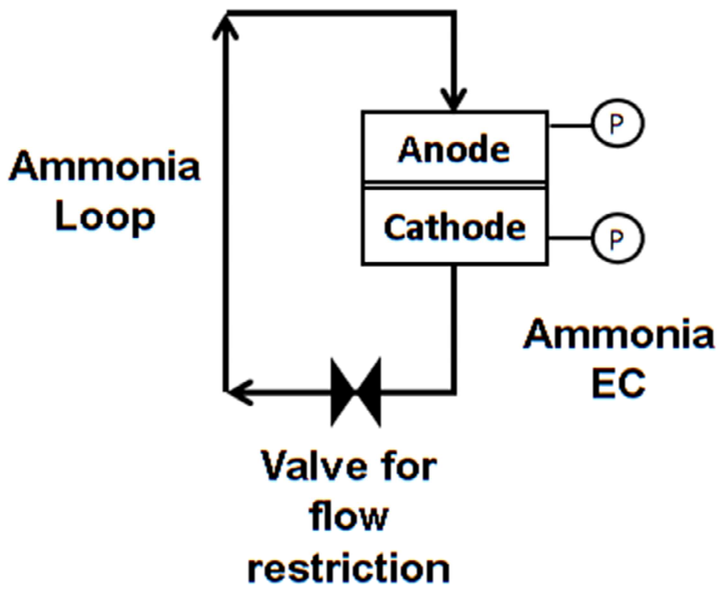
# Open Loop EC Performance

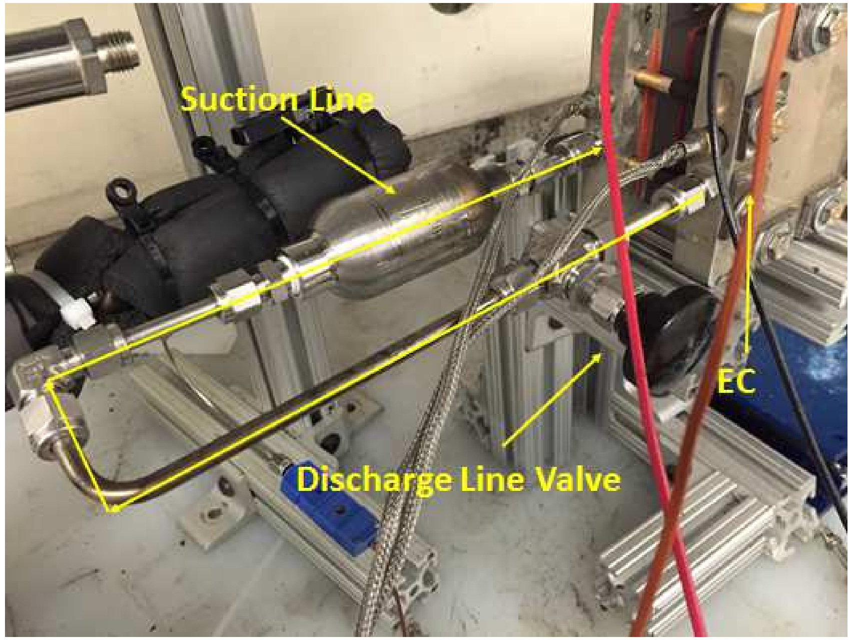



- The discharge line valve is closed
- Partial pressure at inlet and outlet are both calculated
- Voltage charge and partial pressure ratio should follow logarithm relationship

Nernst equation: $$E = \frac{RT}{nF} \ln\left(\frac{P_d}{P_s}\right)$$

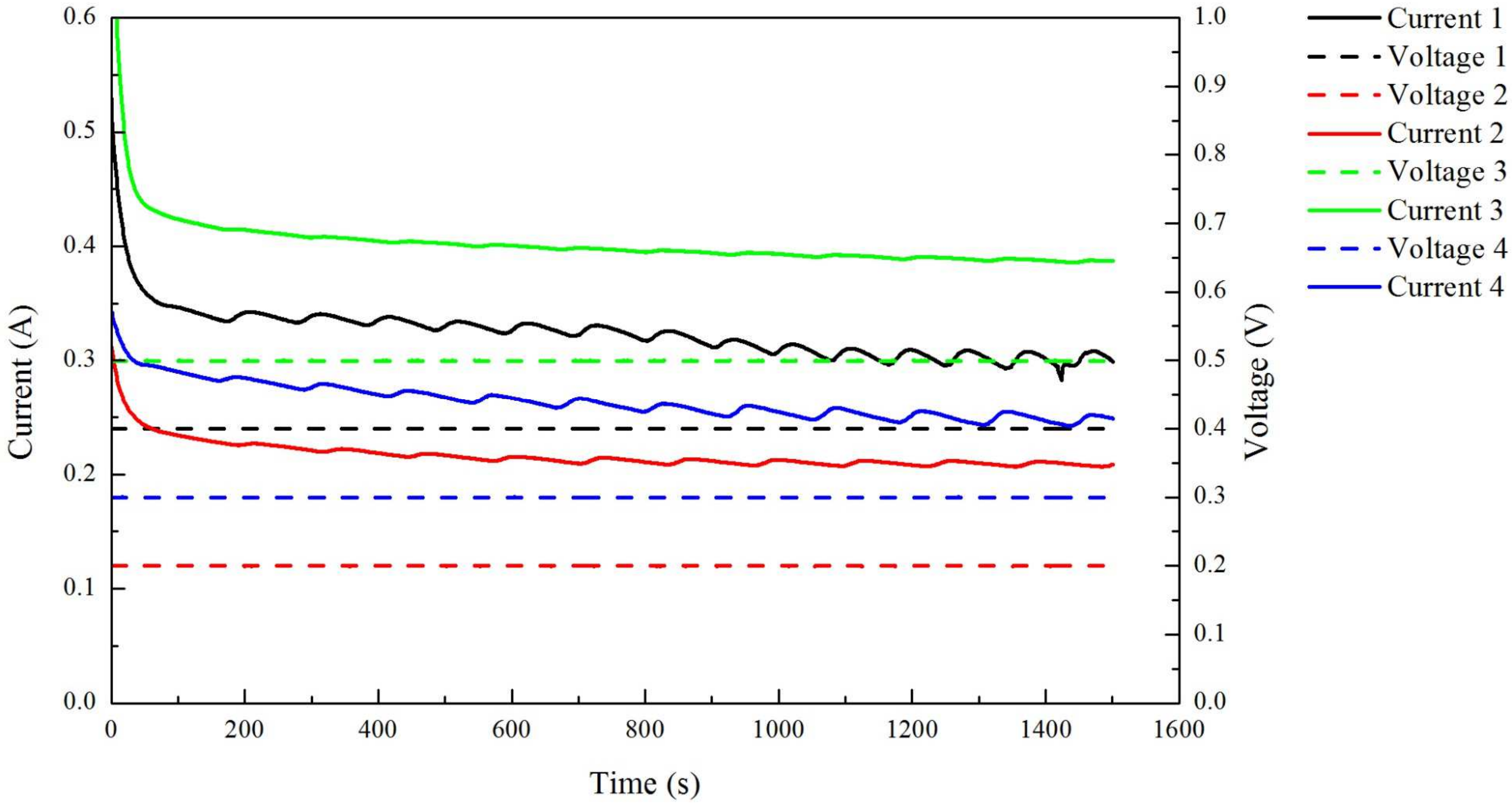
# Closed Loop EC Performance




- Ammonia circulation by EC in a closed loop
- Charged ammonia and hydrogen to 2 bar in the ratio of 2:1
- Voltage charge and current measured
- Pressure lift measured

# Closed Loop EC Performance



# Closed Loop EC Performance

- The flow rate across the EC membrane can be calculated based on the current

Faraday's Law: $\frac{dn_e}{dt} = \frac{I}{nF}$

| Measured Current (A) | Theoretical flow rate $H_2$ ($10^{-6}$ g/s) | Measured flow rate $H_2$ ($10^{-6}$ g/s) | Theoretical flow rate $NH_3$ ($10^{-6}$ g/s) | Measured flow rate $NH_3$ ($10^{-6}$ g/s) |
|---|---|---|---|---|
| 0.14 | 1.45 | 1.85 | 2.47 | 3.22 |
| | 1.45 | 1.72 | 2.47 | 3.16 |
| | 1.45 | 1.78 | 2.47 | 3.29 |

# Closed Loop EC Performance

| Voltage (V) | Pressure lift (kPa) |
|---|---|
| 0.2 | 19 |
| 0.3 | 23 |
| 0.4 | 26 |
| 0.5 | 30 |

- The pressure lift of a single unit is very low
  - Increase linearly as the number of units in the stack increases
- Working conditions for ammonia vapor compression system
  - 5 ºC cooling and 45 ºC heating at 5 bar and 18 bar respectfully
  - EC with multiple units in the stack to achieve desired pressure lift

# Efficiency

- For mechanical compressor

$$\eta_s = \frac{W_s}{W_{MC}}$$

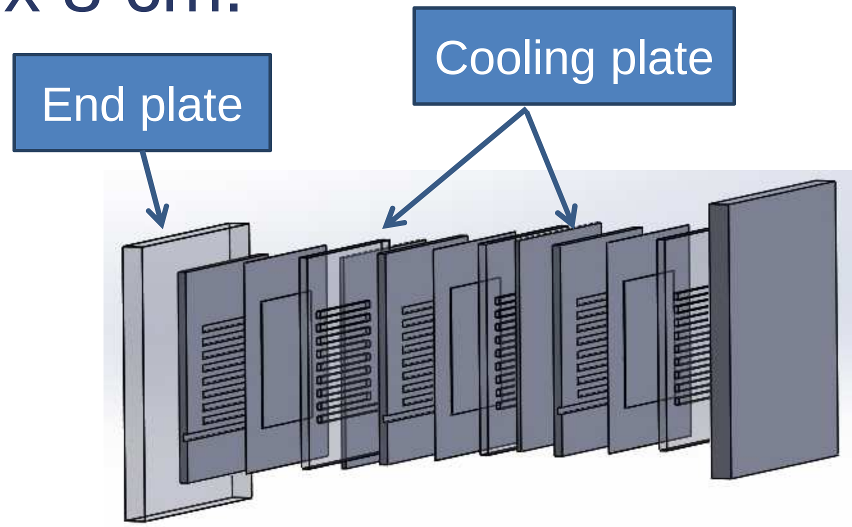
- For electrochemical compressor

$$\eta = \frac{W_{Nernst}}{W_{EC}} = \frac{U_{Nernst}}{U_{EC}}$$

| Voltage Input (mV) | Pressure Ratio | Nernst Voltage (mV) | Efficiency |
|---|---|---|---|
| 50 | 5.5 | 46 | 92% |

# Scale Up and Size Analysis

- For 200 W cooling system, the number of units required is 20.
- Each unit has surface area of 100 $cm^2$ and thickness of 0.4 cm.
- 200 W system would require EC size of 10 x 10 x 8 cm.



# Challenges and Limitations

- Single cell unit flow rate is small
- Flammability of hydrogen used as a carrier gas
- Refrigerant toxicity and flammability
- Moisture in the system

# Conclusions

- The ammonia EC is successfully demonstrated
- The open loop performance can be predicted by Nernst equation
- The EC flow rate can be predicted by Faraday's Law
- The scaled up EC will fit into a 200 W system

# Future Work

- Reduce the stack size by replacing the graphite plates with stainless steel
- Improve the MEA to increase the EC performance
- Build a 200 W EC for vapor compression cycle and test the performance in the system
- Working on alternative refrigerants such as $CO_2$

# Acknowledgement

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***Thank You!***

# Back Up

# Scale up Details

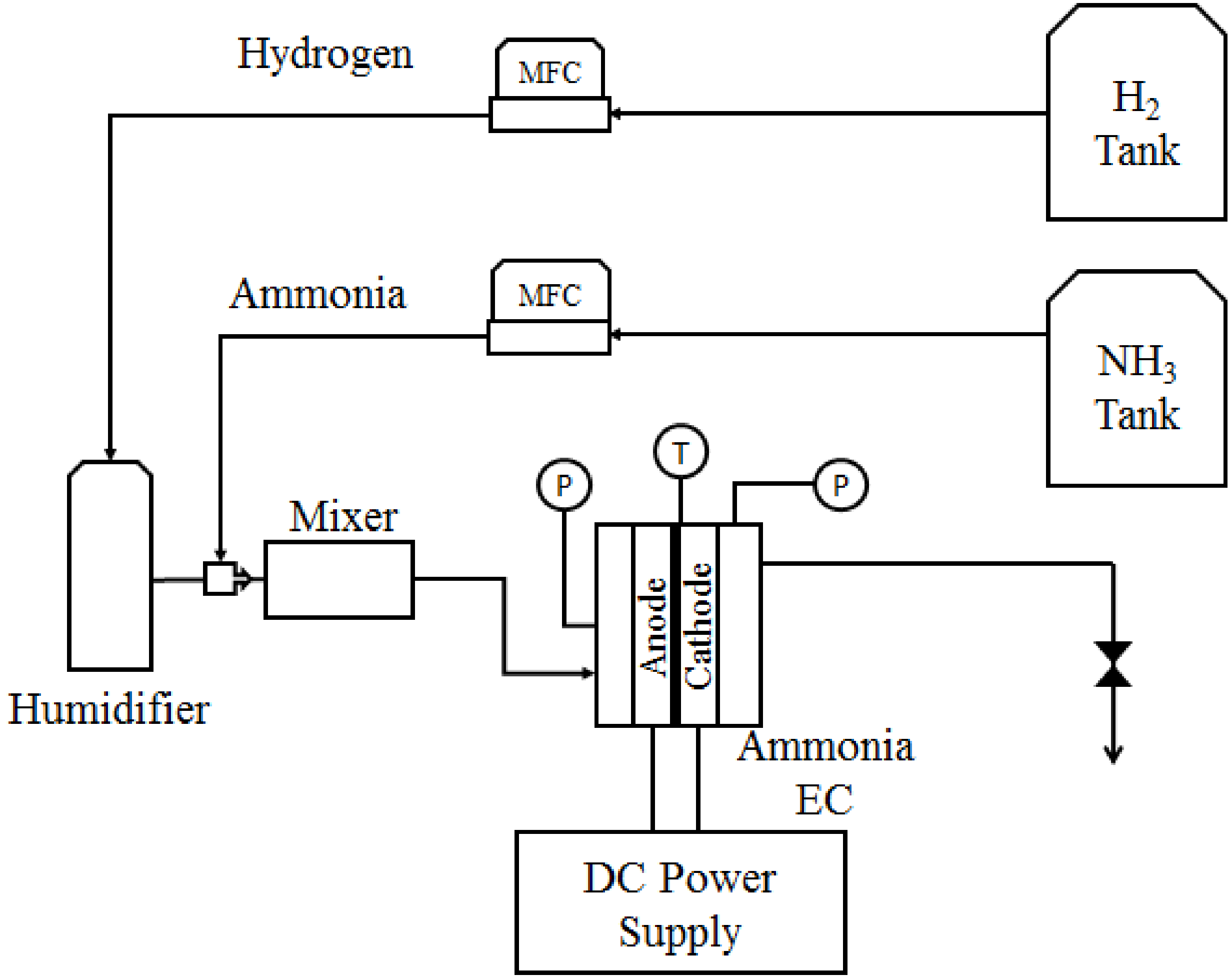
Mass flow rate

$$\dot{m} = \frac{dn}{dt} * M_{NH_3} = \frac{I}{nF} * 17$$

Total current required

$$I = I_d * np * S$$

# Test Facility Schematic



# $CO_2$ Electrochemical Compression