# Direct Ammonia Fuel Cells (DAFCs) for Transport Applications

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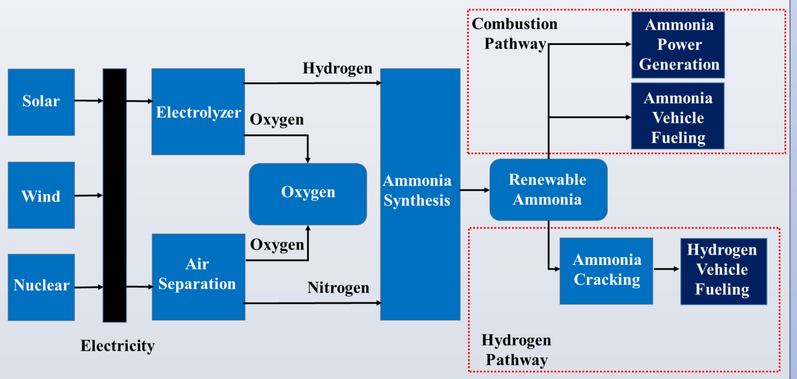
Award No. DE-AR0000805

## Liquid Ammonia as Alternative Fuel

**Derived from Ammonia-Based Energy Storage and Distribution Systems, EPRI Report, 2019**

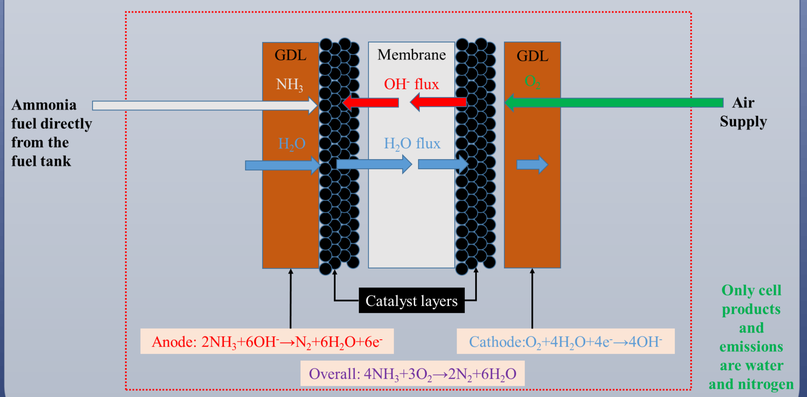



- **Vehicle fueling:** Ammonia is a liquid fuel of high energy density and low storage pressure. These properties facilitate distribution and storage, as required for introduction and acceptance of an alternative fuel.
- **Cost of ammonia:** Distributed as liquid, ammonia is projected to be 30% lower than the cost of hydrogen distributed as compressed gas (UD, 2016)

**ARPA-E funding of work on Ammonia as alternative fuel started in 2017 under the REFUEL Program which includes UD's project on a low temperature fuel cell fueled directly by Ammonia**

## Direct Ammonia Fuel Cells (DAFCs)

**The DAFC Structure and Processes**




**Fuel Cell Powered Electric Vehicle (FCEV)**
**Projected Component Dimensions:**
**Direct Ammonia FC vs Direct Hydrogen FC***

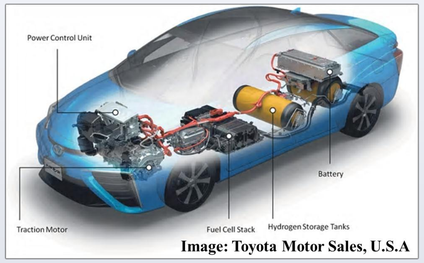



**Image: Toyota Motor Sales, U.S.A**

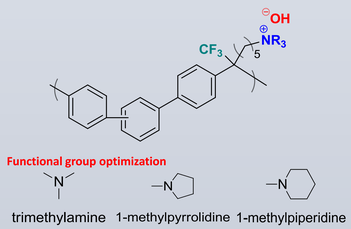
*** Effective Energy Densities:**
**Tank of liquid $NH_3$ ~3.0 kWh/kg**
**Tank of 700 bar $H_2$ ~1.7 kWh/kg**

**Fuel Cell Stack:**
**The DAFC stack will likely be twice as large (+30 L)**

**Fuel Tank:**
**One fuel tank out of the two in the $H_2$-fueled FCEV may not be required in a $NH_3$-fueled FCEV to secure range (-60 L)**

## Novel Hydroxide Exchange Membranes (HEMs)

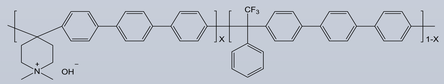
- High performance HEMs are critical to the DAFC concept. HEMs developed for this project offer minimized swelling, high conductivity, high mechanical strength, and high alkaline stability near 100 °C.



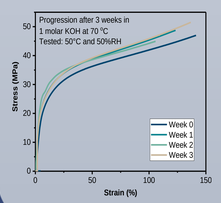

| Property | Value |
|---|---|
| Thickness | 25 µm |
| Water uptake (r.t.) | 24% |
| Swelling degree (X) (r.t.) | 2% |
| Swelling degree (Y) (r.t.) | 5% |
| Resistance ASR (80 °C, 100% RH) | 0.12 Ω·cm² |

## Best Membrane Developed For Polymer Electrolyte DAFCs

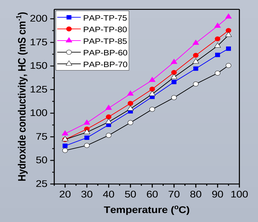
PAP-TP-X (UD)




### High Strength

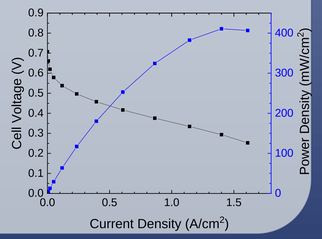



### High Conductivity




### Record DAFC Performance

(100 °C, 2 mg PGM /cm²)




## Record DAFC Performance in the REFUEL Program

- Operating near 100 °C with thin HEMs and optimized catalysts enabled demonstration under the ARPA-E Program of highest direct ammonia fuel cell performance reported to date.
- Presently demonstrated 400 mW/cm² of cell active area will enable volumetric peak power density near 0.8 kW/L allowing effective packaging in a passenger vehicle (higher power densities likely to be achieved upon further development).
- The main remaining challenges are:
  - Lower PGM catalyst loading to lower DAFC cost
  - Minimize fuel losses

## Early Market Applications: DAFCs Can Provide a Simple & Compact Power Source for Drones

- Fuel cell (FC) systems have higher energy density than the demonstrated batteries. However, gaseous fuel storage at ultra-high pressure is a challenge.
- Ammonia can be fed directly to a DAFC operating near 100°C.

**Weight and volume of 2 kW / 8 kWh drone power system**

| Drone Power System | Rechargeable Battery | Hydrogen FC Power System | Our DAFC Power System |
|---|---|---|---|
| Filled Tank or Fully Charged Battery Weight (kg) | 40 | 11.4 | **5.6** |
| System Weight (kg) | 40 | 16.3 | **11.4** |
| System Volume (L) | 20 | 37.9 (300 bar) | **15.8** |
| Tank pressure (bar) | N/A | 200 – 700 | **10** |
| Refill /Recharge | Lengthy | Challenging | **Simple** |

## Conclusions

- With ammonia recognized recently as the fuel to be widely made from renewable energy resources, the DAFC developed in the REFUEL program can become the preferred type of power source when using this alternative fuel.