Ammonia-Fueled Electric Vehicle

- Given ammonia fuel for use in vehicles , the choice of a fuel cell for energy conversion results in an ammonia-fueled **electric vehicle**.

  This choice recognizes that electrification of automotive power systems is a strong trend projected to strengthen further in the near future.

  Along these lines, first generation of commercial **FCEVs** has been introduced in 2015.

Preference of a "direct" ammonia fuel cell

- In the FCEVs manufactured to date the fuel cell operates on direct feed of fuel from the tank, with no pre-processing on board.

  To large degree, hydrogen became a preferred fuel for automotive fuel cells because , unlike many other fuels, it can be used in a "direct" fuel cell

- The direct mode of operation seems to be a prerequisite for successful reduction to practice of FCEVs.

  This is explained by system simplicity and a higher efficiency secured by the single stage conversion process

The same reasoning applies to targeting of
direct ammonia fuel cells
for conversion of the chemical energy of ammonia
to electric energy

Toyota Mirai as Baseline

UNIVERSITY OF DELAWARE

FC昇圧コンバーター
Fuel cell boost converter

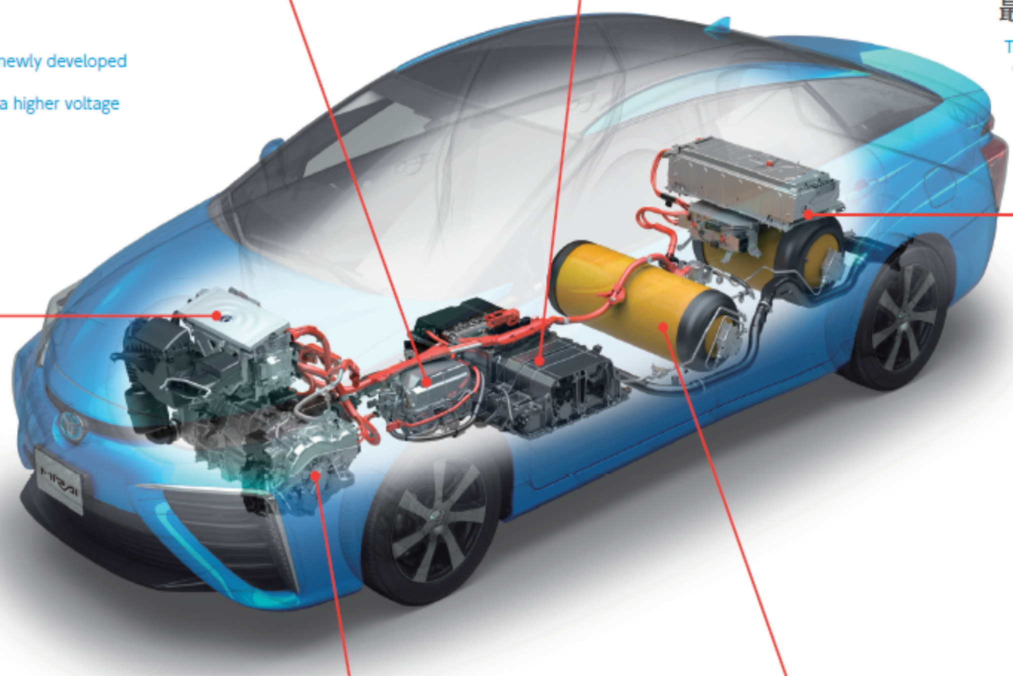
FCスタックの電圧を650 Vに昇圧する、小型・高効率の大容量コンバーターを新開発。
昇圧コンバーター：入力電圧よりも高い電圧で出力を得るための装置。

A compact, high-efficiency, high-capacity converter newly developed to boost fuel cell stack voltage to 650 V.
A boost converter is used to obtain an output with a higher voltage than the input.

FCスタック
Fuel cell stack

トヨタ初の量産型燃料電池。小型化と世界トップレベルの出力密度を実現。
体積出力密度：3.1 kW/L
最高出力：114 kW (155 PS)

Toyota's first mass-production fuel cell, featuring a compact size and world top level output density.
Volume power density: 3.1 kW/L
Maximum output: 114 kW (155 PS)



駆動用バッテリー
Battery

減速時に回収したエネルギーを貯蔵し加速時にはFCスタックの出力をアシストするニッケル水素バッテリー。

A nickel-metal hydride battery which stores energy recovered from deceleration and assists fuel cell stack output during acceleration.

パワーコントロールユニット
Power control unit

あらゆる運転状況下でFCスタックの出力と駆動用バッテリーの放充電を最適に制御するための装置。

A mechanism to optimally control both fuel cell stack output under various operational conditions and drive battery charging and discharging.

モーター
Motor

FCスタックで作り出した電気と駆動用バッテリーからの電気で駆動するモーター。
最高出力：113 kW (154 PS)
最大トルク：335 N·m (34.2 kgf·m)

Motor driven by electricity generated by fuel cell stack and supplied by battery.
Maximum output: 113 kW (154 PS)

高圧水素タンク
High-pressure hydrogen tank

燃料となる水素を蓄えるタンク。公称使用圧力は高圧の70 MPa (約700気圧)。世界トップレベルのタンク貯蔵性能を達成し、軽量・小型化。
タンク貯蔵性能：5.7 wt%

Tank storing hydrogen as fuel. The nominal working pressure is a high pressure level of 70 MPa (approx.700 bar). The compact, lightweight tanks feature world' s top level tank storage density.

The Rationale for the DAFC as Power Source for Transport

Q.

With all first generation FCEVs manufactured to date with hydrogen fuel cells and H_2 gas (at 700 bar) on board, why pursue DAFC technology for EVs?

A.

- 1. Ammonia being a liquid under low pressure at ambient T , the infrastructure of fuel distribution and refueling should be much simpler and significantly less costly vs. the infrastructure for compressed hydrogen delivery and refueling.

- 2. A direct ammonia fuel cell would use $NH_{3,liq}$ of energy density ~6kWh/kg_{NH3} and for the electric power system, providing the demand power , energy content , energy conversion efficiency and zero emissions targetted for future automotive applications

*The energy density of a tank of compressed H2 at 700 bars is ~1.7 kWh/$kg_{full\ tank}$

Choice of Alkaline Membrane Fuel Cell Technology for DAFCs in Transport Applications

DAFC Specs Needed to Secure Competitive Performance in FCEV:

- **Peak Power Density at least 50% of the DHFC**
- **Conversion efficiency , ammonia chemical energy-to-mechanical energy to the wheels, over 40% at 25% of peak power**
- **Max. start-up time of several minutes , requiring lower temp. FC technology (< 120 degC)**
- **Zero tail-pipe emissions -- more readily achieved with a low T DAFC technology**

The Solution pursued in our Project:

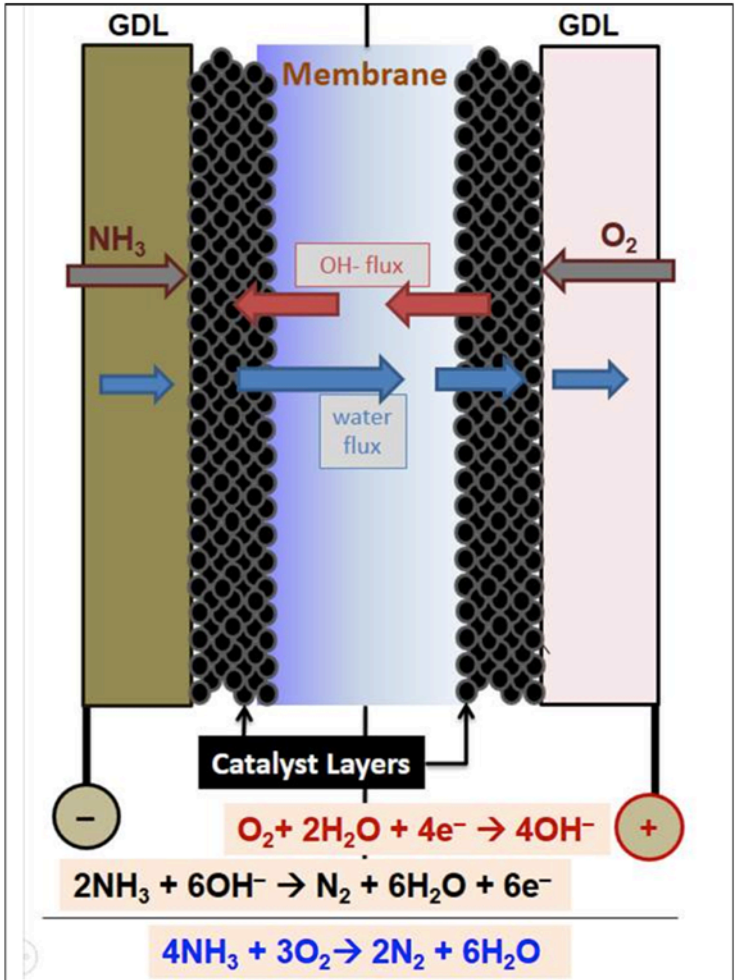
- **Alkaline Membrane Fuel Cell Technology at Tcell near 100 degC**

Main Technical Requisites for Reduction to Practice

- **Catalyst for Ammonia Electro-oxidation of high activity at 100 degC**
- **Alkaline membrane of good chemical stability at 100 degC**

Electrode Reactions and Net Cell Process in a Direct Ammonia Fuel Cell

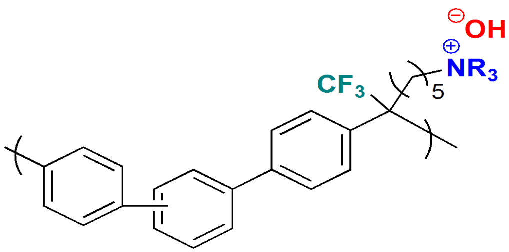
Cell emissions are only N_2 and H_2O



Development of Alkaline Membranes (RPI & Xergy)

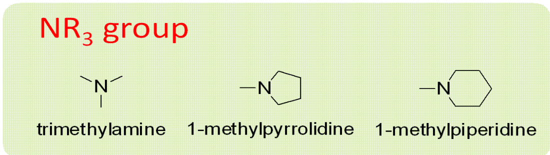
Novel polymer structues for DAFC Membranes

(a)

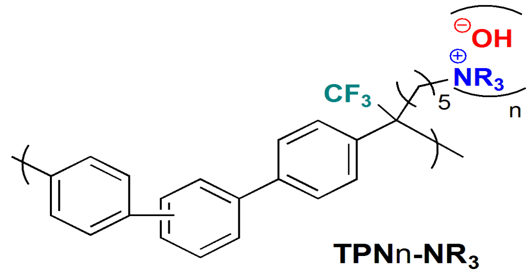


TPN1-NR$_3$

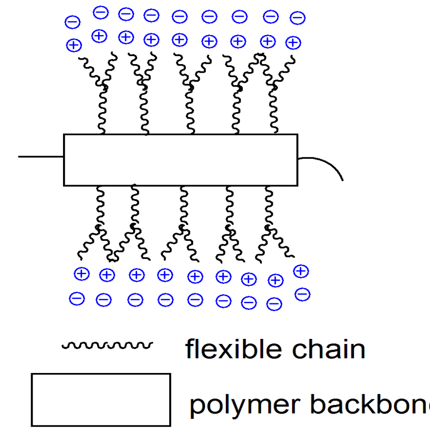
TPN1-TMA for trimethylamine



(b)



TPNn-NR$_3$



Targets:

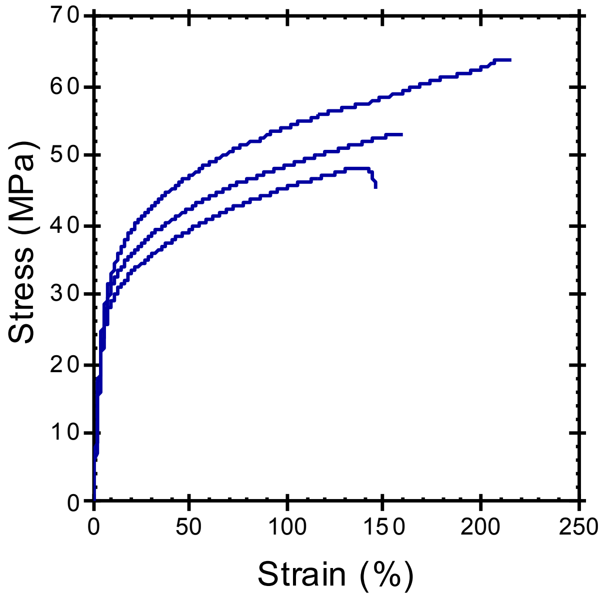
1. Enhanced chemical stability at high pH and 100 °C while improving ion conductivity
2. Low dimensional swelling and permeation of fuels
3. Enhanced HEM mechanical strength

Development of Alkaline Membranes (RPI & Xergy): GEN1 Reinforced Composite Alkaline Membrane

Membrane properties of GEN1 reinforced composite membrane, TPM1-TMA on microporous polyolefin mesh

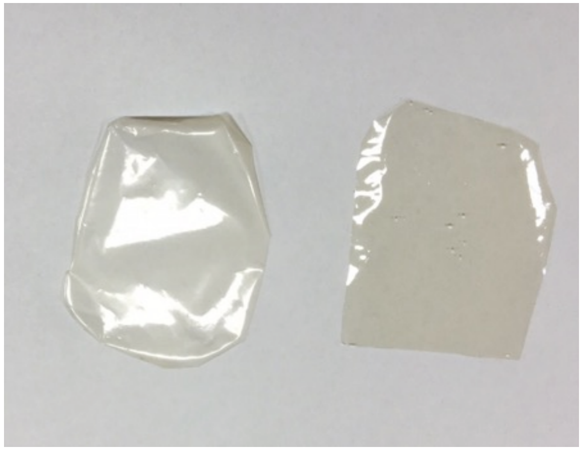
Thickness	Water uptake[a]	Swelling degree[a] X,Y dimension	Through-plane ASR[b]
~25 µm	24%	2% and 5%	0.15 Ω·cm^2

[a] Measured before and after immersion in 1 M KOH for 24 h at room temperature
[b] Measured at 80 °C, 100% RH in MEA with hydrogen gas at both electrodes. OH^- generated in-situ by hydrogen pumping



Mechanical property test of reinforced composite HEM

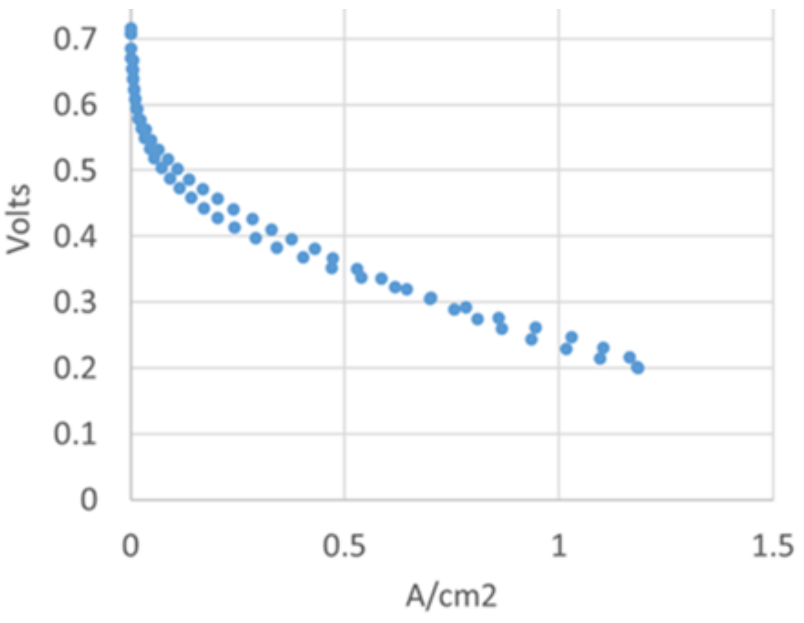
Ultimate Tensile Strength
target: 10 MPa
status: 50 MPa

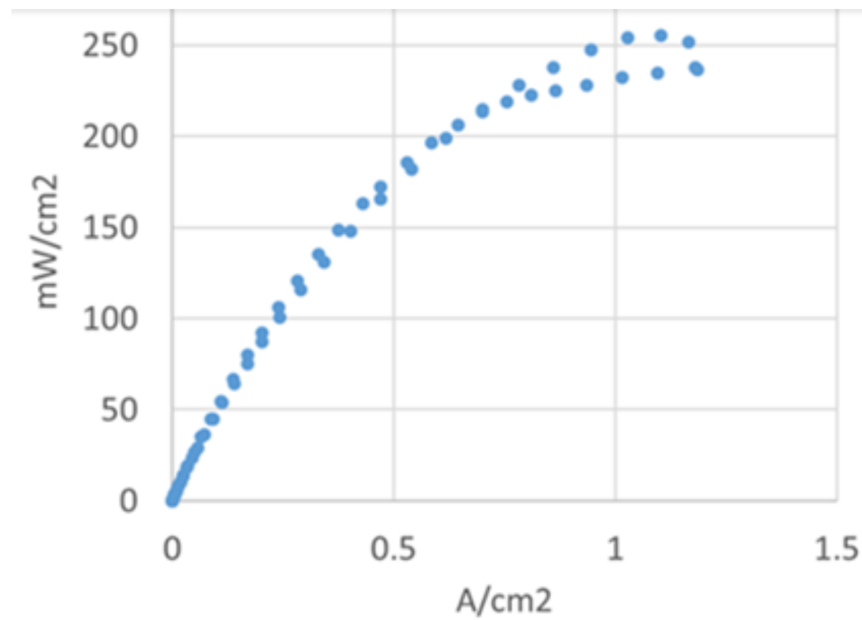


Reinforced composite TPN1-TMA HEM

Early Development of DAFC Catalyzed Membranes in the ARPA-E Project (Udel & PoCell)

90 degC Performance of a DAFC with an Alkaline Membrane Electrolyte



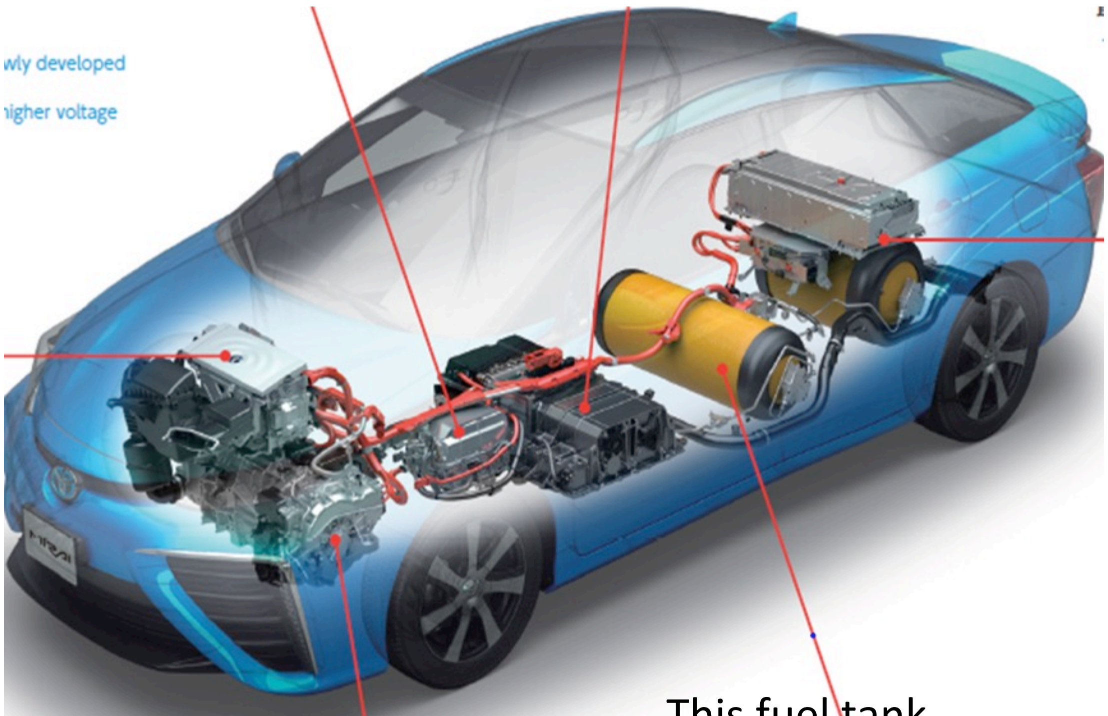


***** x10 higher DAFC performance than reported to date *****

DAFC specs targeted likely to be hit on raising cell T to ~120 degC

Projected Component Dimensions: Direct Ammonia FC vs Direct Hydrogen FC

The FC stack will likely be twice as large **(+30L)**



This fuel tank
out of the two used in the Mirai
may not be required at all **(-60L)**

Summary

- Recent development of polymer electrolyte DAFCs has yielded promising cell performance, supporting the prospects of this fuel cell technology to become a viable power source for electric vehicles
- Advanced Membranes and Membrane/Electrode Assemblies (MEAs) developed in this Project assist in securing future supply of key DAFC components
- The advantages of liquid ammonia as fuel over compressed hydrogen gas include a simpler and cheaper fuel infrastrutue, as well as significantly higher energy density impacting favorably system dimensions

Feedback Request

We will appreciate comments of all types from potential users of DAFC technology with ammonia as the fuel carried on board including possible applications for automotive, stationary and UAV power

Shimshon Gottesfeld
1-518-506-0177
Shimshon.gottesfeld@gmail.com

THANK YOU FOR YOUR ATTENTION