Innovative Fuel Cells

Next Generation Components for HT PEM and their Relevance in Marine Applications

IEA Technology Collaboration Programme,
Advanced Fuel Cells
November 2025

Organization

30 Employees

38 Successful R&D Programs

70+ Patents Issued, Licensed, or Pending

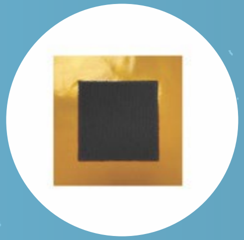
Advent Overview

Advent Technologies GmbH
Kehl, Germany

- Office

Advent Technologies LLC
Silicon Valley, USA

- Corporate Headquarters
- Portable Fuel Cell Products R&D and Production
- DIGI-TRONIC fuel cell system R&D
- Development of advanced cooling technologies



Advent Technologies SA,
Athens, Patras and Kozani, Greece

- Ion Pair™ MEA product development
- Fuel Cells R&D and production
- Electrolyzers R&D and production
- MEA production

The Next-Gen Fuel Cell

No need for expensive hydrogen infra

Competition

Typical low-temp fuel cell

Requires 99.99% pure hydrogen. Infrastructure for storage, transportation, refill is very expensive

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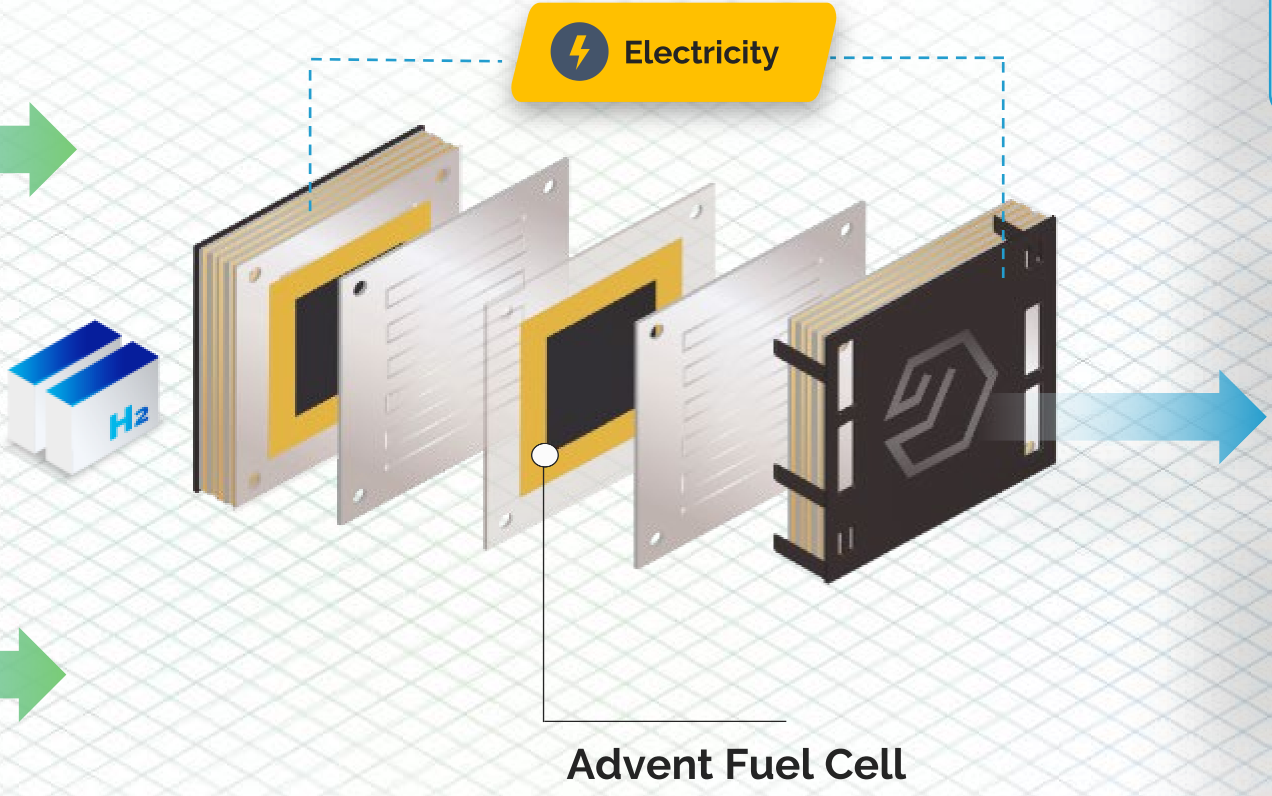
(green) methanol, biofuels, ammonia and other hydrogen carriers



Electric Vehicles

Off-Grid Power Generation

Aviation: Drones, eVTOLs

Marine, Aux. Power

Comparison

Battery Only
vs
Advent's Fuel Cell Electric Power System

Comparison based on 1 day (6MWh/day load) trip

Battery Only System

Advent's Electric Power Systems

7 times lower weight than battery only
35% less space required
3 times lower cost

Comparison based on 3 day (6MWh/day load) trip

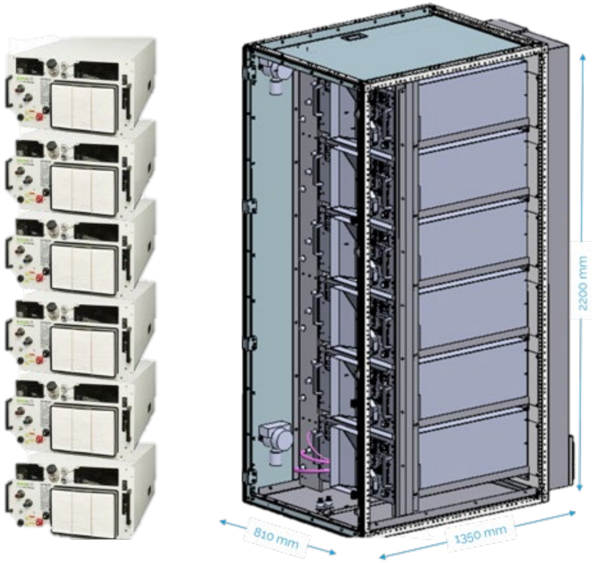
Battery Only System

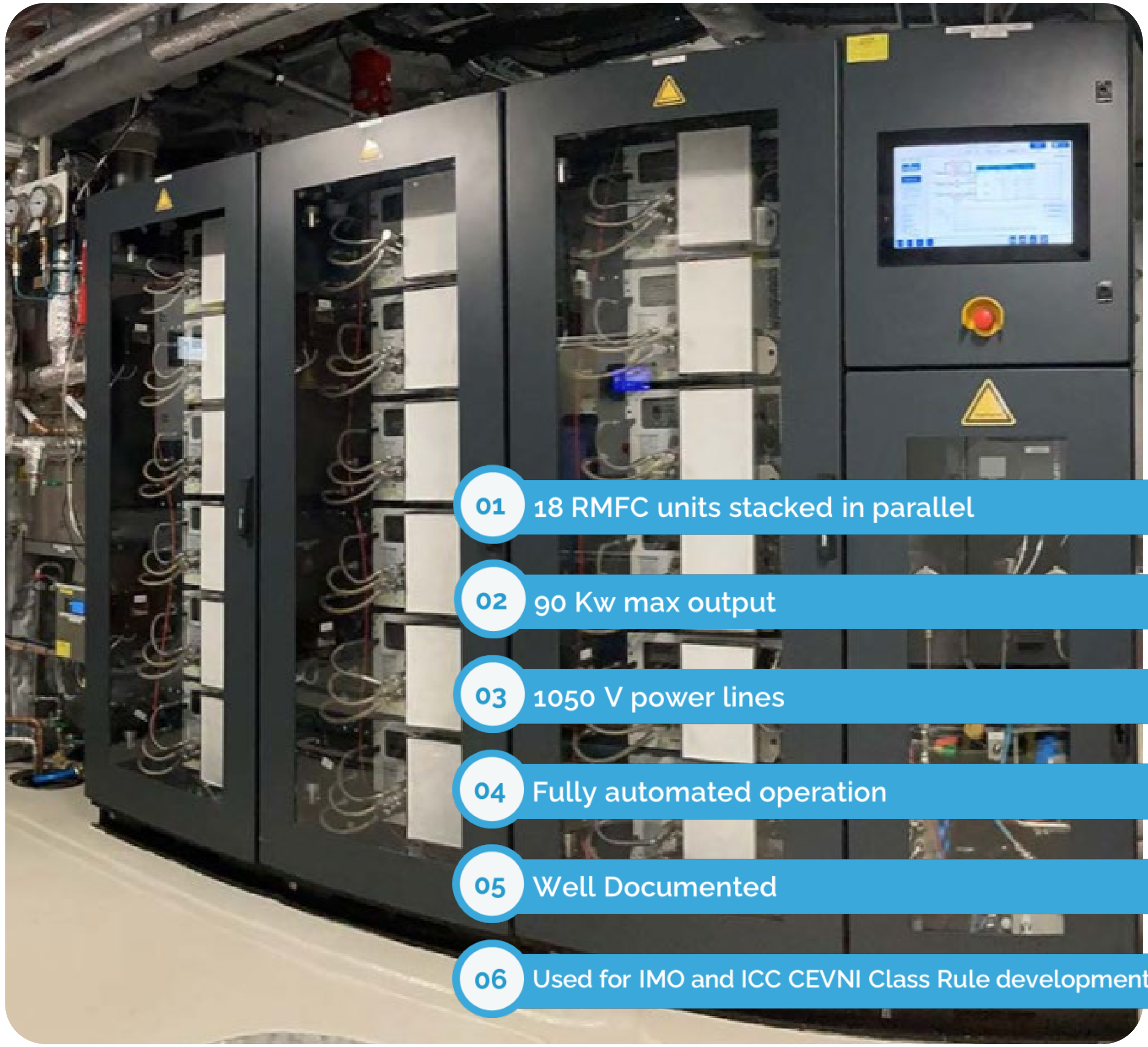
Advent's Electric Power Systems

13 times lower weight than battery only
72% less space required
9.4 times lower cost

Legacy Projects: RiverCell 90 kW Integrated Solution in Neptun Werft Shipyard

90 kW installation RiverCell II
1 x base + 3 x FC Racks





- 01 18 RMFC units stacked in parallel
- 02 90 Kw max output
- 03 1050 V power lines
- 04 Fully automated operation
- 05 Well Documented
- 06 Used for IMO and ICC CEVNI Class Rule development

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Methanol= Liquid Green Fuel and Excellent Green Hydrogen Carrier

- **Grey methanol**: Derived from natural gas, undergoing an electrochemical conversion process to produce power (and heat) in fuel cells.
- **Biomethanol:** Sourced from biomass, waste, or biomethane via gasification methods.
- **eMethanol:** Produced through a combination of green hydrogen, generated via water electrolysis using renewable power sources, and CO_2.

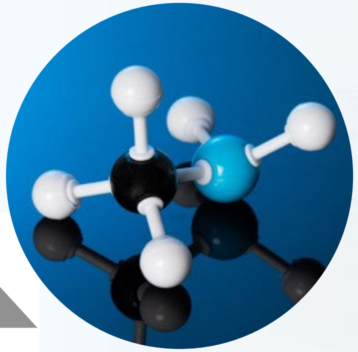
Bloomberg — **Maersk Unveils World's Biggest Methanol-Powered Container Ship**

Splash 247.com — Orders for methanol engines outpace LNG for the first time

REUTERS — Shipowners, port operators ramp up methanol-fuelling projects

DNV — Methanol as fuel heads for the mainstream in shipping

Methanol is the Fuel of Tomorrow, Available Today



130
Green Methanol production projects underway 60% e-methanol, 40% bio-methanol

20m tons
Production Capacity 2028

251
Methanol-fueled vessels are either actively in service or on order.

Types Of Methanol Vs Diesel

Advent Fuel Cells can also use H2 or natural gas, ethanol

Fuel	Cost vs Diesel	TCO/kWh (incl. capex, service, fuel)	CO2 Emissions	Pollutants
Diesel		€€€ 0.6-1.15	CO_2 1,162 gr/kWh	Unburned Hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), SOx, particulate matter (PM), BC, OC
Grey Methanol	€ % 60%-80%	€ 0.41 in 2026	CO_2 605 gr/kWh	No SOx, NOx, PM2.5, BC, OC
Biomethanol	€ % 30%-40%	€€ 0.59 in 2026	CO_2 232 gr/kWh	No SOx, NOx, PM2.5, BC, OC
eMethanol	= Parity by 2035 or at H_2=$4.5/kg	€€ 0.59 in 2035	CO_2 18 gr/kWh	No SOx, NOx, PM2.5, BC, OC

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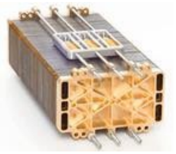
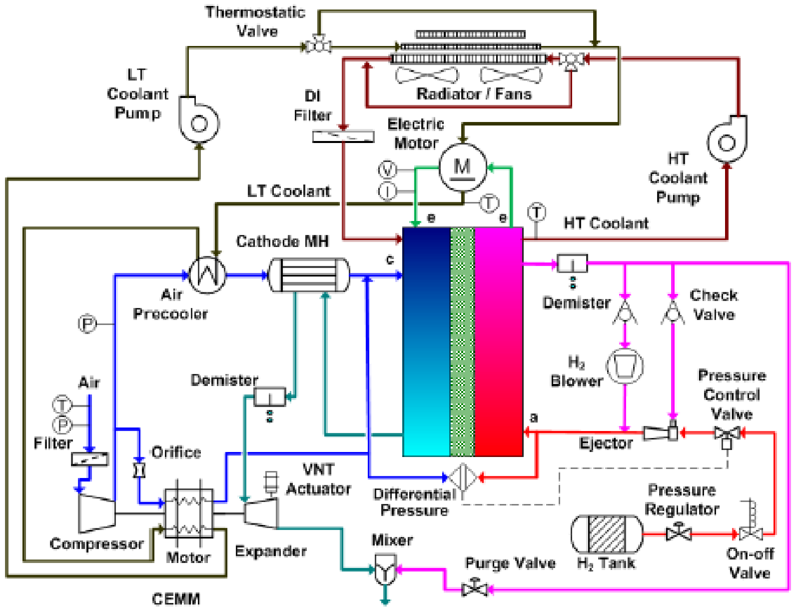
Technology comparison

COMPARISON	COMPETITION Low Temperature Proton Exchange Membrane **LT PEM** **33% efficiency**	ADVENT High Temperature Proton Exchange Membrane **HT PEM** **45% efficiency**
FUEL 	**Methanol** ✓	**Methanol** ✓
EVAPORATOR 	**Energy loss** approx. 5 % X	**Using** stack **waste heat** ✓
REFORMER 	**Expensive** reformer and gas purification X	 Simple and **cost efficient** ✓
GAS PURIFIER 		Not necessary ✓
FUEL CELL 	Must have **99,99x% H_2** X	Can function down to **70% H_2**. Ideal for methanol, up **3 % CO** ✓

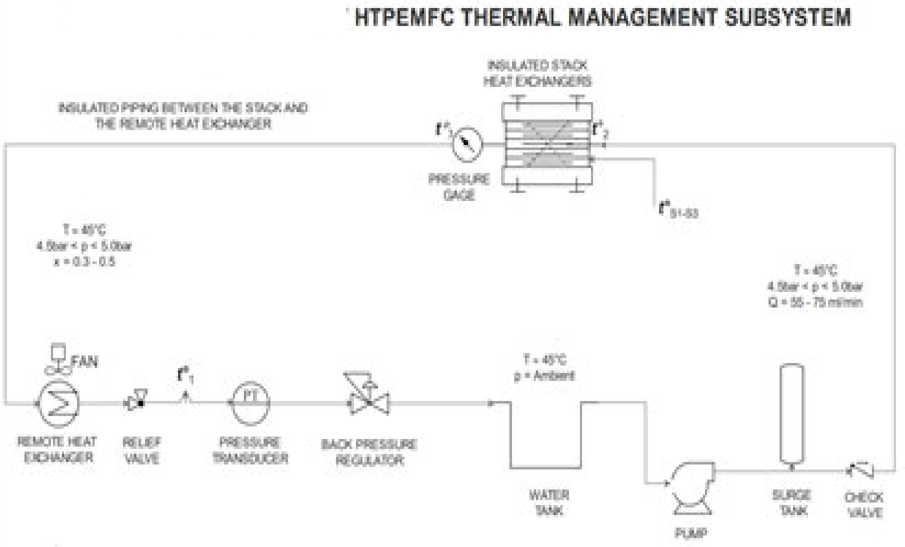
System simplification with HT PEM

External cooling with 2-phase (liquid vapor) flow of water-(or other benign fluid)

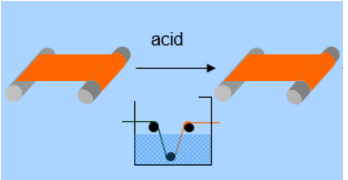
- Eliminates problematic oils typically used as coolant
- Cooling effectiveness of latent heat transfer is much better compared to sensible heat transfer
- 2-phase flow assures exact constant temperature
- Smaller low power pump
- Smaller volume of coolant due to highly effective latent heat transfer
- Small piping circuit components
- Edge, not internal cooling

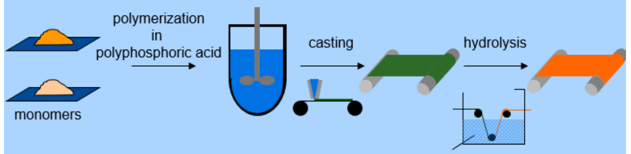


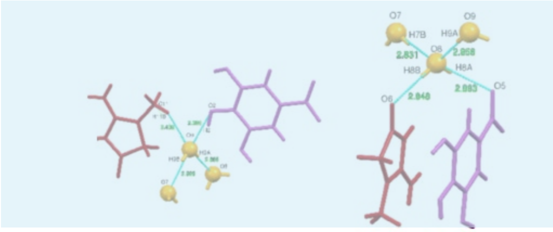
LT PEM System, from Ahluwalia



Primer on HT PEM



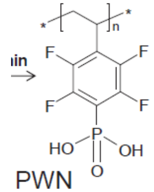




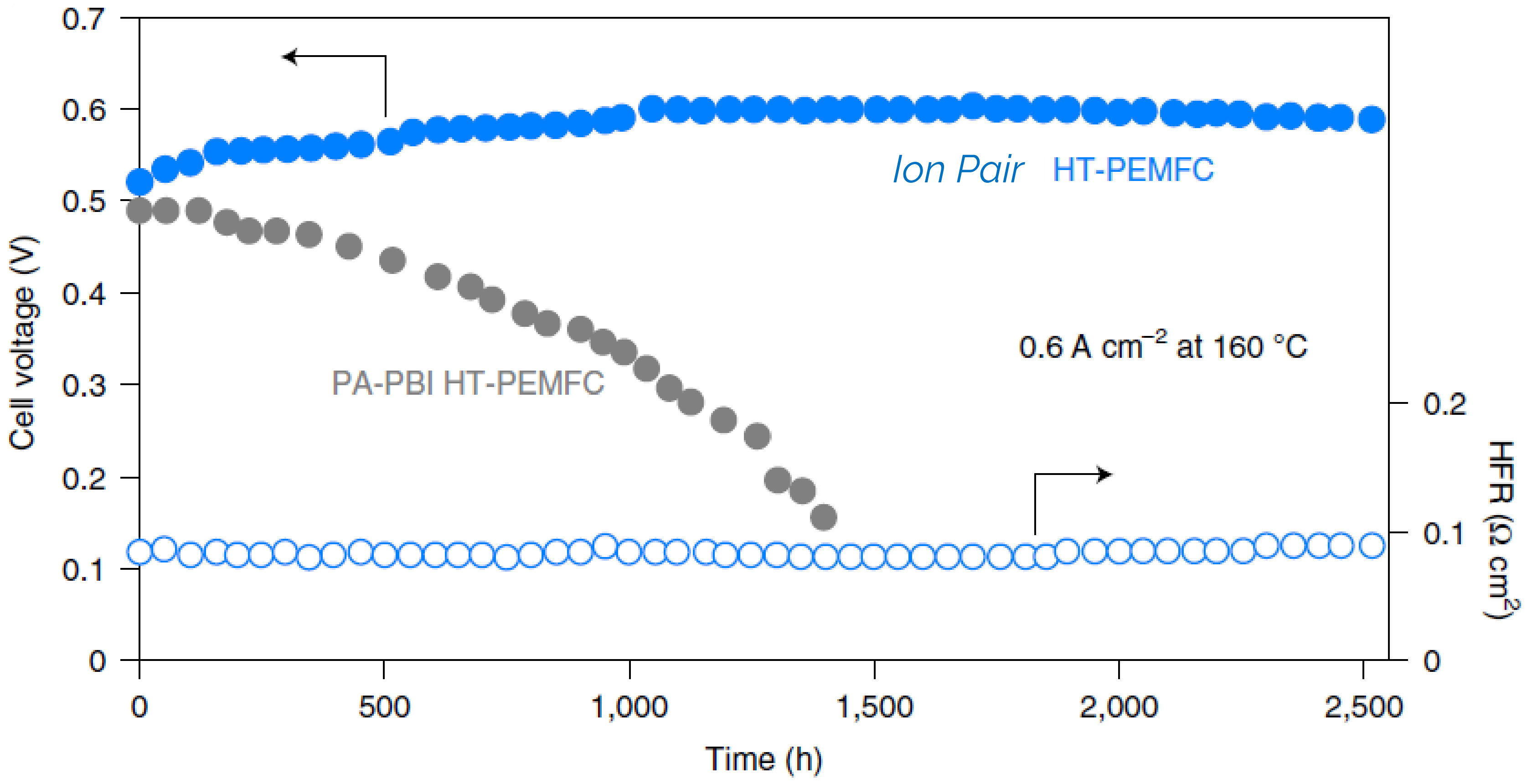
Generation	I 1990s, Case Western, Savinell "PBI"	II ~2004, RPI, Benicewicz & Calundann, "PPA PBI"	III ~ 2018, LANL, Kim et al. "Ion Pair"
How it is made	Dip *m*-PBI engineering polymer into phosphoric acid	Polymerize *p*-PBI in the presence of polyphosphoric acid. Hydrolyze.	Dip anion exchange membrane into phosphoric acid . Forms tight ion pair complex
Advantages	First to demonstrate HT PEM, moderate acid loading that is loosely bound to membrane	Very high acid loading. Improved lifetime and performance	Low loading of tightly bound acid. Can make MEAs that have architecture closer to LT PEM. Demonstrated higher power and lifetime than Gen II
Disadvantages	Thick membrane, not capable of higher power. Lower acid meant limited lifetime.	Control of acid leaching Thick electrodes and membrane > 200 ˚C reverts to gel Still limited life at higher power output	Full potential not realized

DOE HT-PEM MEA is portfolio of technologies (L'Innovator)

DOE technology provides a path for HT PEM to be competitive with LT PEM

Membrane	• Ion-Pair is new paradigm for HT PEM • Led by strong computational modelling to predict favourable ion-pairs • Backed up by synthesizing the structures and testing: identified optimum • More water tolerant vs TPS or PBI	For example, functionalized DAPP (AEM) from Sandia National Laboratory (M. Hibbs, C.H. Fujimoto, et al.)
Binder /electrolyte	• "Decoupled ionomer" • Structure of ionomer (binder) is not same as membrane • Can design for higher oxygen flux	For example, phosphonic acid functionalized poly(pentafluorostyrene) (V. Atanasov, J. Kerres, et al)  PWN
Catalyst	• Stabilized Core shell (Brookhaven National Laboratories) • High activity • Robust to cycling	Multi-component intermetallic internal core, thin platinum shell

Lifetime, single cell, 5 cm2 (at Los Alamos)



High air flow to accelerate degradation

Published in Nature Energy 2022

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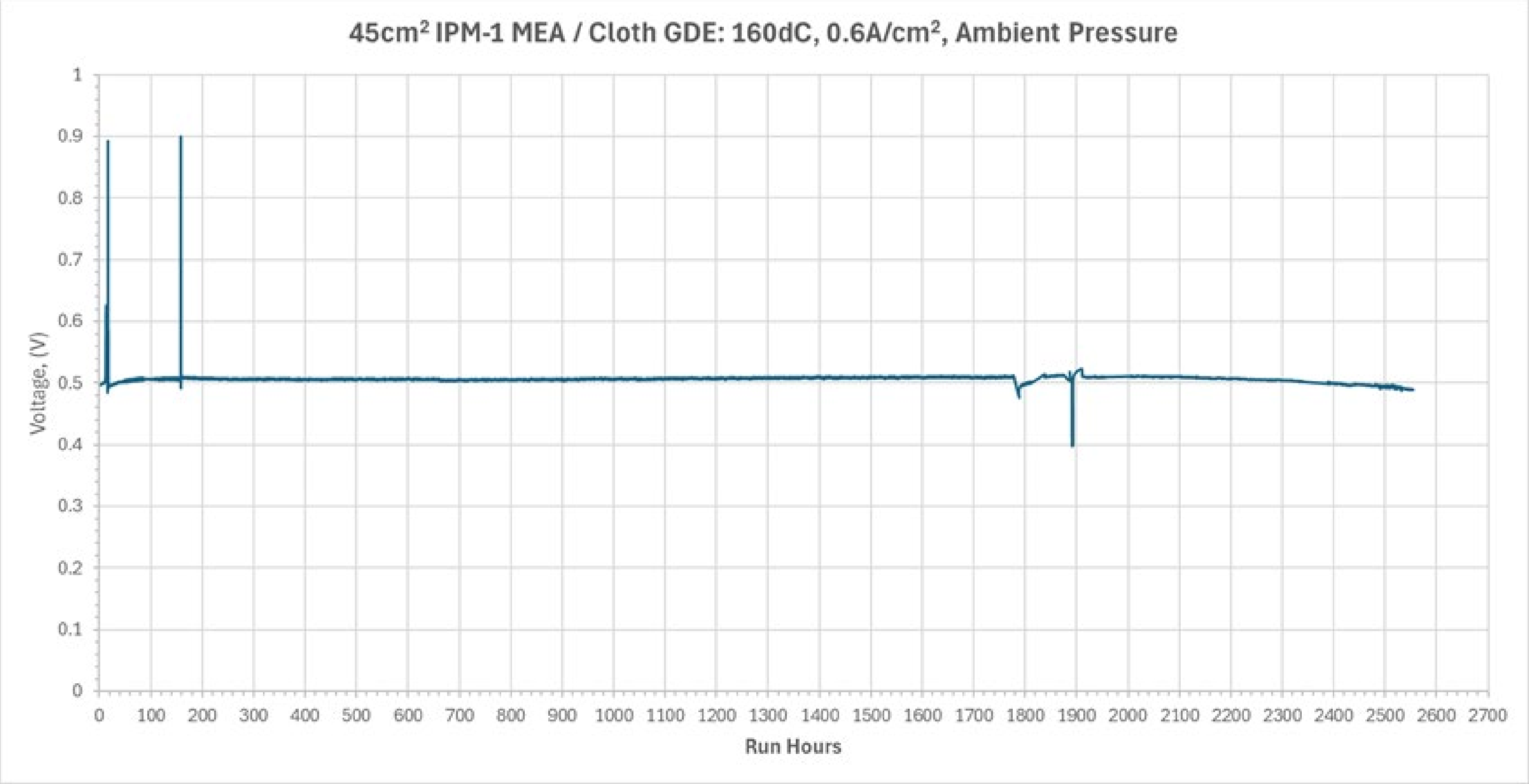
Lifetime, single cell, 45 cm², industrialized MEA



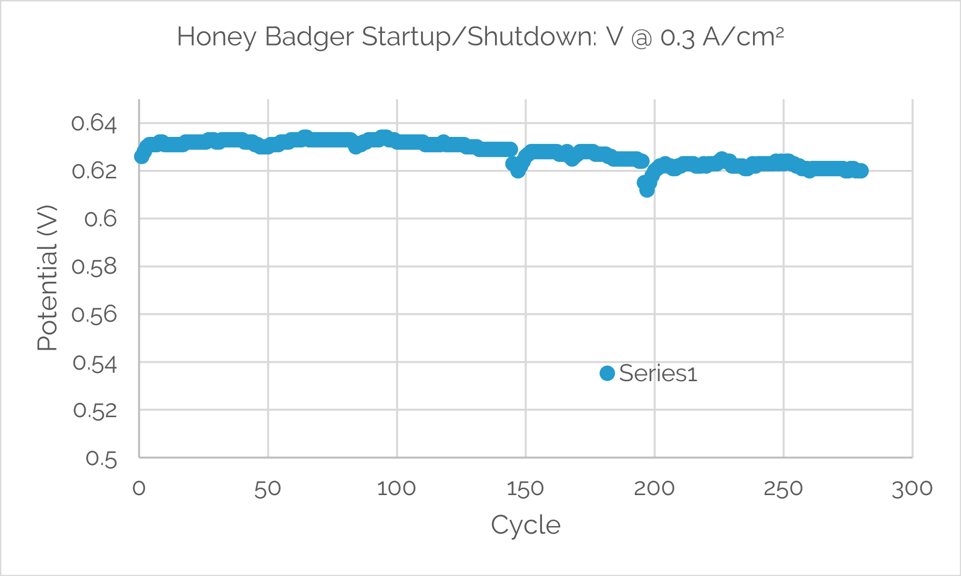
Forth uncontrolled shutdown at 2,550 hrs led to failure

- Ion Pair -4.2 uV/hr after 2500 hrs.
- Under these condition prior generation (PBI) closer to -8 uV/hr with failure > 1,000hrs

65 cell stationary stack with Ion Pair
(165 cm^2 active MEAs)
Similar lifetime

Lifetime, on/off single cell

Single Cell at 45 cm² active area
- Standard Materials, ambient pressure, H_2/Air,
- Achieved 0.02mV/cycle drop after 280 cycles vs. 0.5mV/cycle for PBI



- 50 W battery charger
- Integrated methanol reformer
- Can reduce energy weight in the field by 75% vs only batteries (72 hour mission)

- *Ion Pair allows 30 % reduction in mass and 27 % reduction in volume vs 2022 soldier unit w PBI*

Outstanding resilience to off/on cycling

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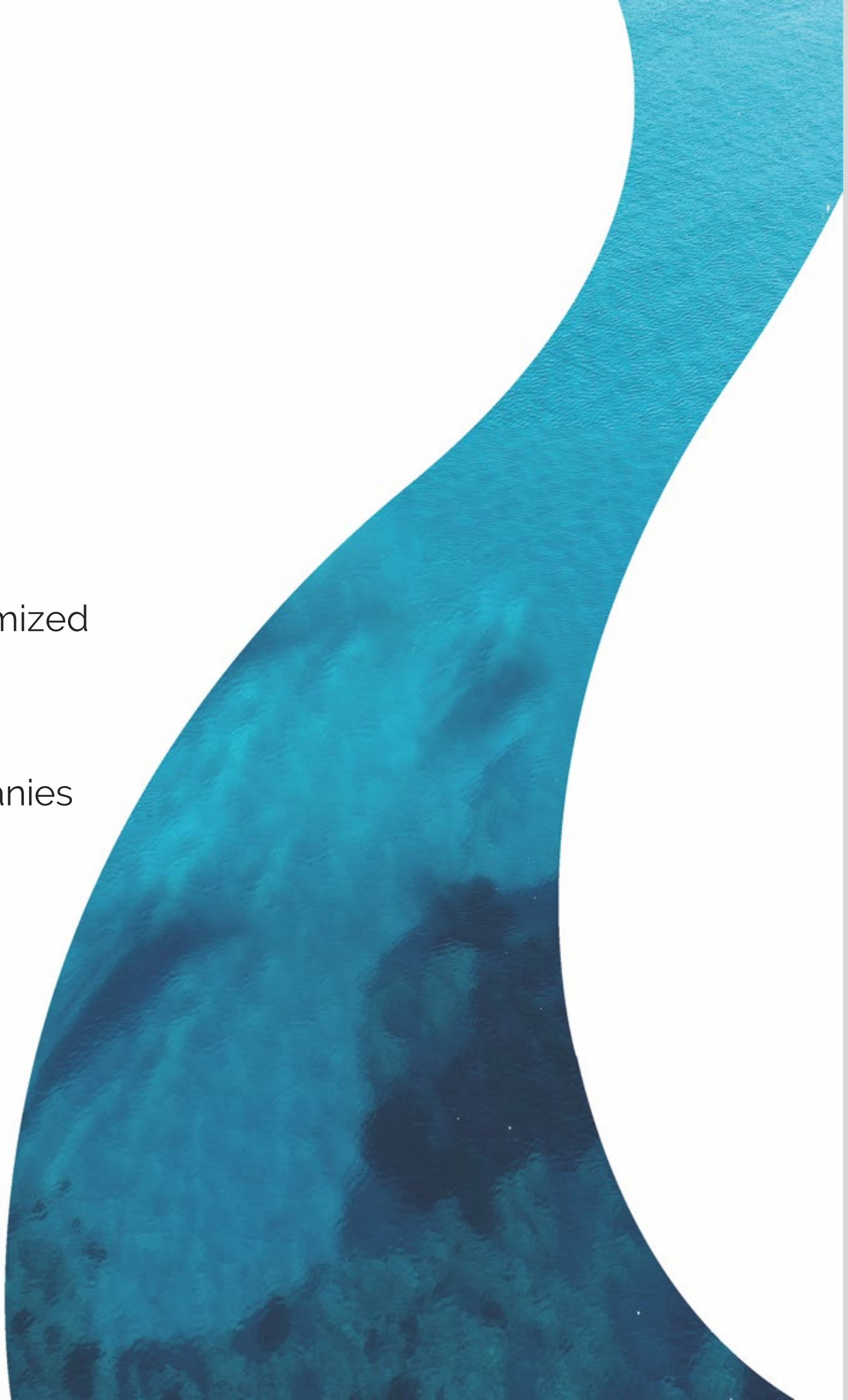
Forging Strategic Alliances For Joint Business Development

Advent forges **strategic alliances** for customized product development with:

- Shipyards
- Ship design and engineering companies
- Propulsion and power machinery producers
- Propulsion, energy and automation systems designers and integrators
- Fuel infrastructure, Hydrogen, and methanol fuel suppliers
- Classification societies
- National laboratories

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