Fuel Cell / Battery Hybrid Systems for UAV Applications

H_2@Airports Workshop
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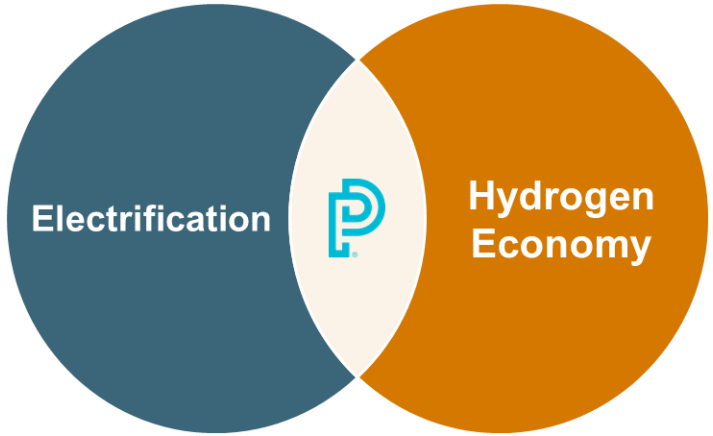
Plug Power is a Leader in Hydrogen and Fuel Cell Technology

- 1st to create a market for HFC technology
- 31.4MM+ vehicles fueled; 35T+ liquid H_2 used daily
- 40,000 units deployed by year end 2020
- GenKey end-to-end solution provides fuel and H_2 infrastructure, fuel cells and service
- Expansion into electrolyzers and green hydrogen plants via acquisitions
- In-house capability to become one of the largest green hydrogen generators over the next several years



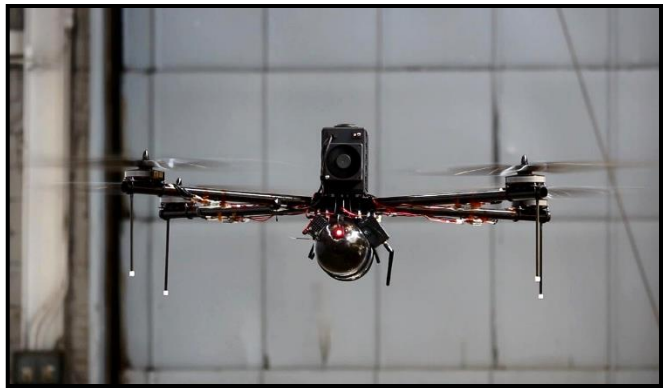
Some Plug Power UAV History…

First Fuel Cell UAV in Canada (2007)

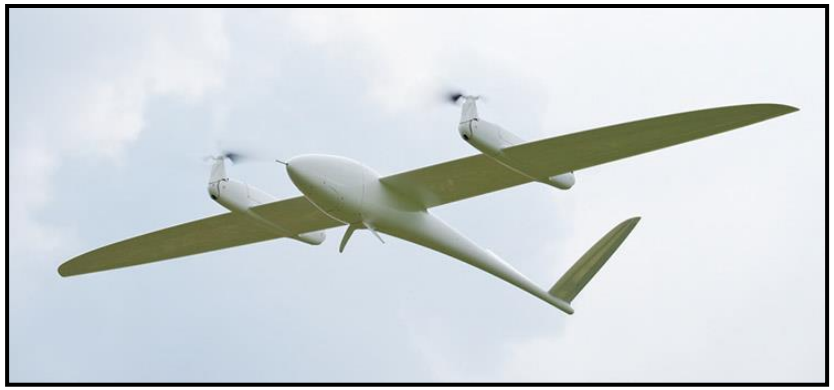
First Fuel Cell UAV in Israel (2007)

10 Hour Endurance - Canada (2011)

First Fuel Cell Multirotor Flights in the World (2015)



Longest Fuel Cell Multirotor Flights in the World (2015)



First Fuel Cell eVTOL UAV in the World (2017)

UAV Fuel Cell Systems & Platforms

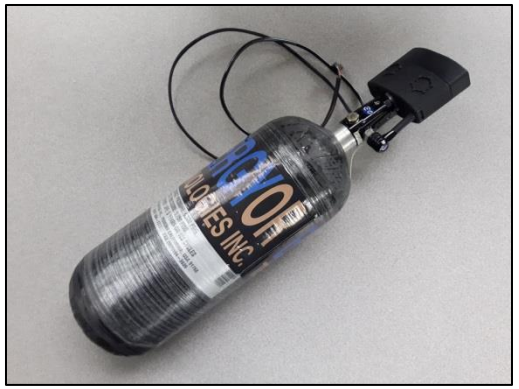
EnergyOr - H_2Quad 1000

EO-310-LE*

EO-310-XLE**

(Now ProGen 300W)

Fuel Cell System



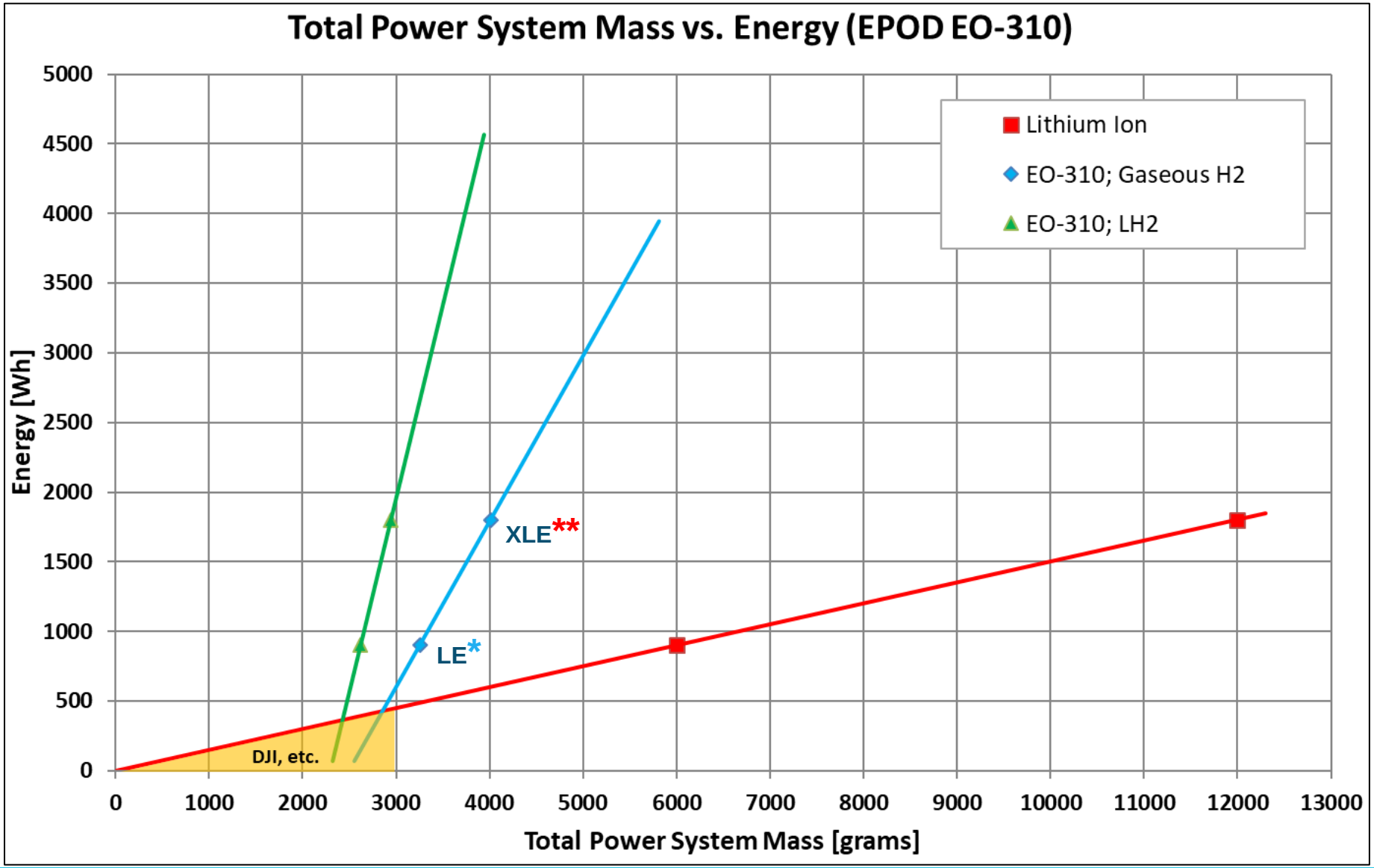
* EO-310-LE ** EO-310-XLE

Hydrogen Delivery System

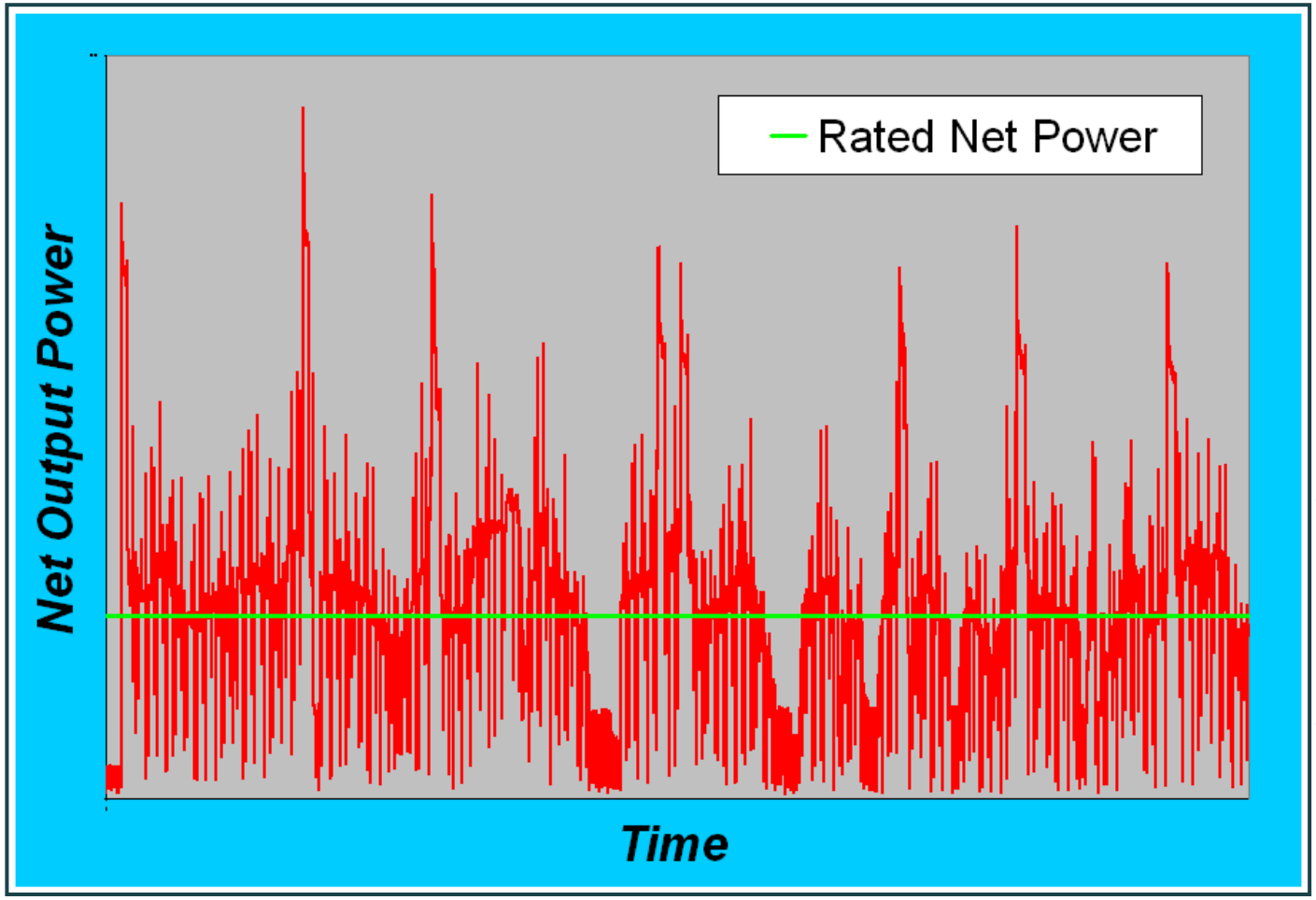
Quantum Systems - TRON

Hybrid Battery

Why Fuel Cells for UAV / Aerospace?



Advantages of Hybridization



Power Source	Specific Power [W/kg]	Specific Energy [Wh/kg]
LiPo Batteries	++	+
Fuel Cell Systems	+	++
Hybrid Fuel Cell / LiPo*	++	++

Hybrid Battery Supplements FC Power

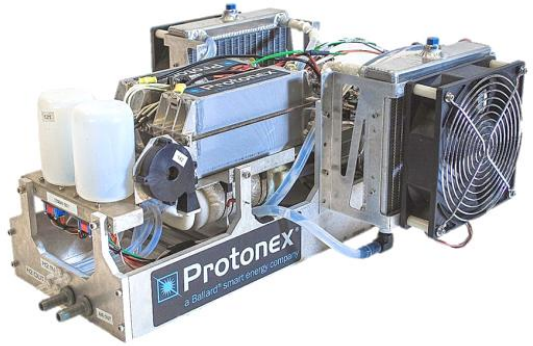
Hybrid Battery Charging with Excess FC Power

* Hybrid systems can be highly optimized for a given duty cycle

Fuel Cell Architectures for UAVs

Type	Advantages	Disadvantages
Air Cooled Open Cathode	Very lightweight *No air compressor*	Low altitude
	Simple	Lower ambient temperatures
	No external humidification required	Cathode contamination *Up to 200x reactant air for cooling*
	Easiest to scale	Cell pitch / packaging space

Type	Advantages	Disadvantages
Liquid Cooled Closed Cathode	Higher altitude	Heavier *Air compressor; cooling module*
	Higher ambient temperatures	More complex
	Higher cell current density *At expense of cell efficiency*	If freeze capable, WEG coolant required, making radiator larger
	Low cathode contamination	Humidifiers required
	Easier to scale	Packaging space



Type	Advantages	Disadvantages
Air Cooled Closed Cathode	Simple	Heavier *Air compressor*
	Higher altitude	Less easy to scale >1kW
	Higher ambient temperatures	
	Low cathode contamination	
	Low cell pitch - reduced packaging space	
	Freeze capable with no system design impact	
	High system level efficiency	
	No external humidification required	

ProGen Technology Advantages for UAVs

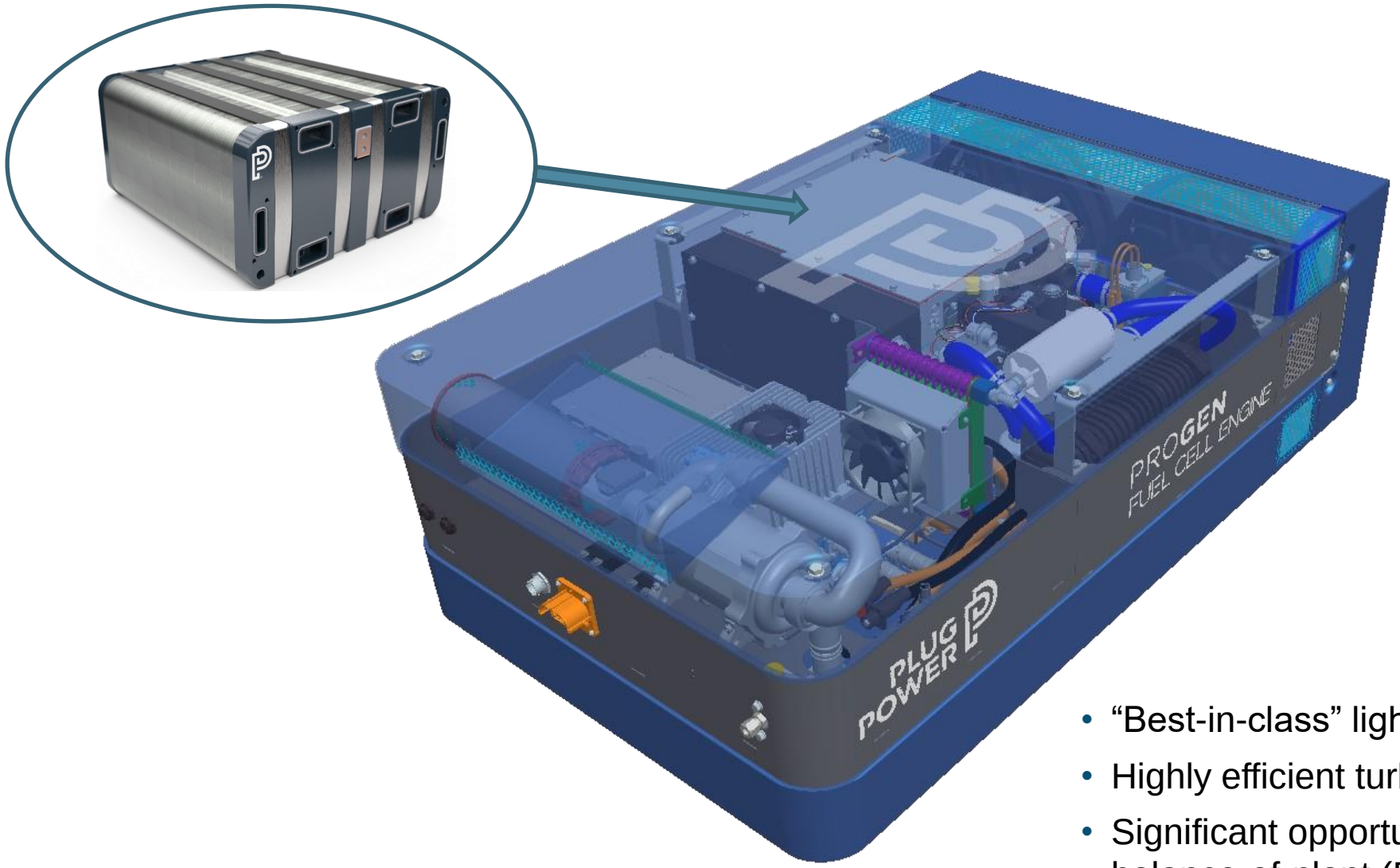
- Versatile, light-weight, closed-cathode, air-cooled fuel cell platforms
- Fuel cell / battery hybrid with high specific power (W/kg) & specific energy (Wh/kg)
- Significantly longer operational endurance than LiPo batteries (of same mass)
  - Gaseous Hydrogen => 3 to 4 times
  - Liquid Hydrogen => 6 to 9 times
- Reduced logistics and operational costs
- Broader mission capabilities
- Ability to power more energy intensive payloads

ProGen 1kW System Development – “Flying Testbed”

Where ProGen 1 kW Adds Value Today

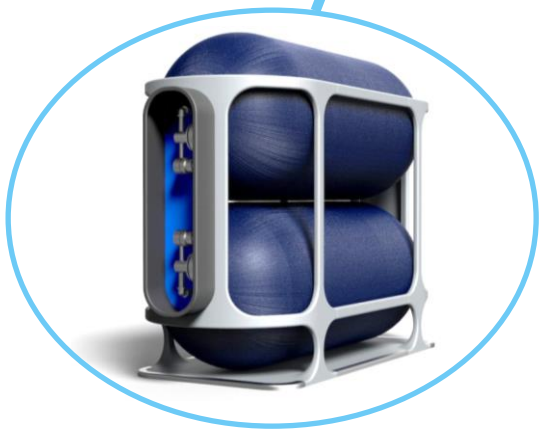
- Long endurance
- Fleet applications
- Centralized fueling
- High utilization => commercial / industrial
- Fast-fill
- Reduced maintenance (compared to IC engines)
- Zero-emission

ProGen 30 kW, 125 kW and Beyond…

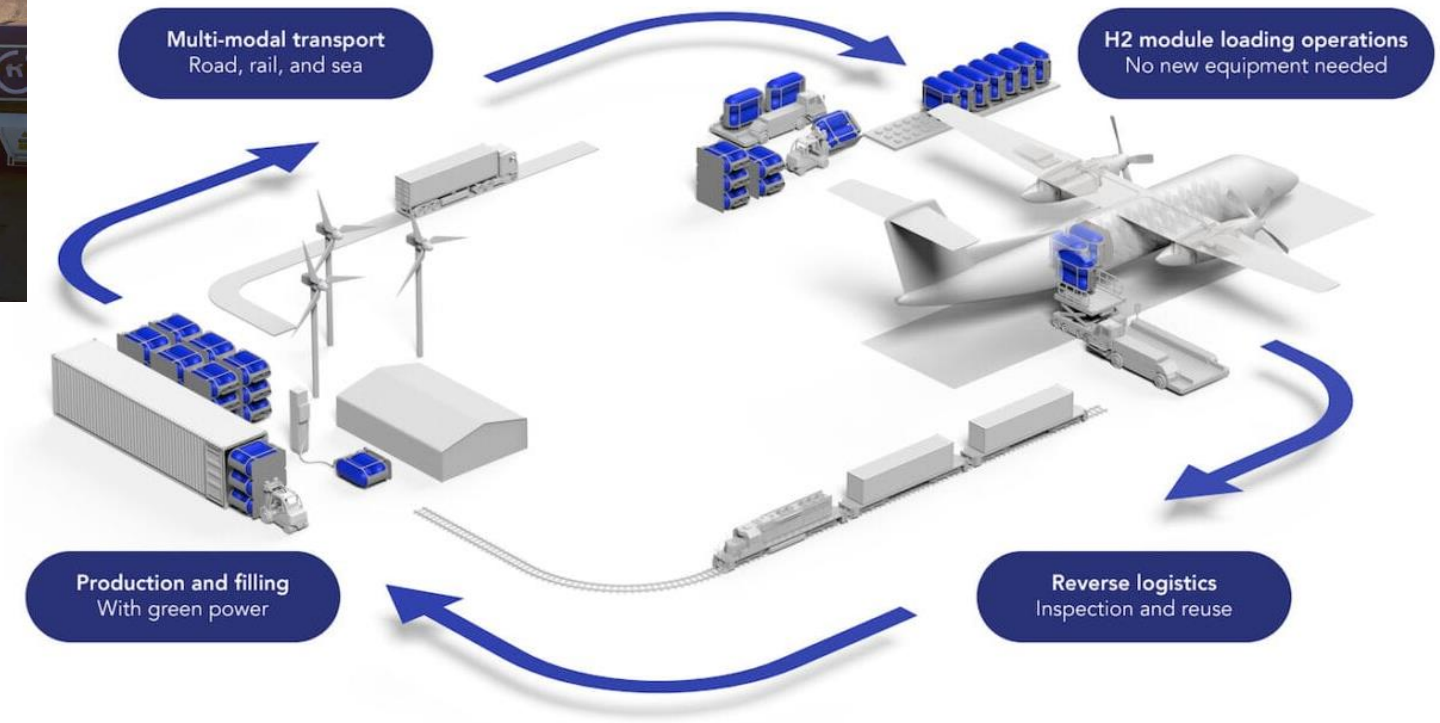


- “Best-in-class” lightweight metal plate stacks
- Highly efficient turbo-compressors
- Significant opportunity to reduce weight of balance-of-plant (BOP)

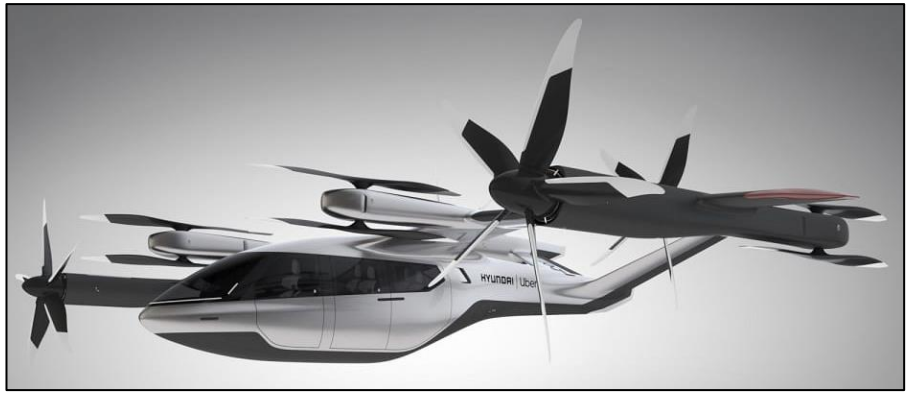
Plug Power / Universal Hydrogen Partnership



- **Dash 8-300 / ATR 42 fuel cell powered regional aircraft**
- **2 MW per side**
- **Gaseous H_2 @ 850 bar (400 nm) & LH_2 (550 nm) fuel pods available**



For Aerospace Fuel Cells…The Future is “Light”



Urban Air Mobility

Cargo Delivery

Medical Supply Delivery

Commuter Aircraft

Pseudo-satellites

Regional Aircraft

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