# DEVELOPMENT OF A HIGH RELIABILITY COMPACT AIR INDEPENDENT PEMFC POWER SYSTEM

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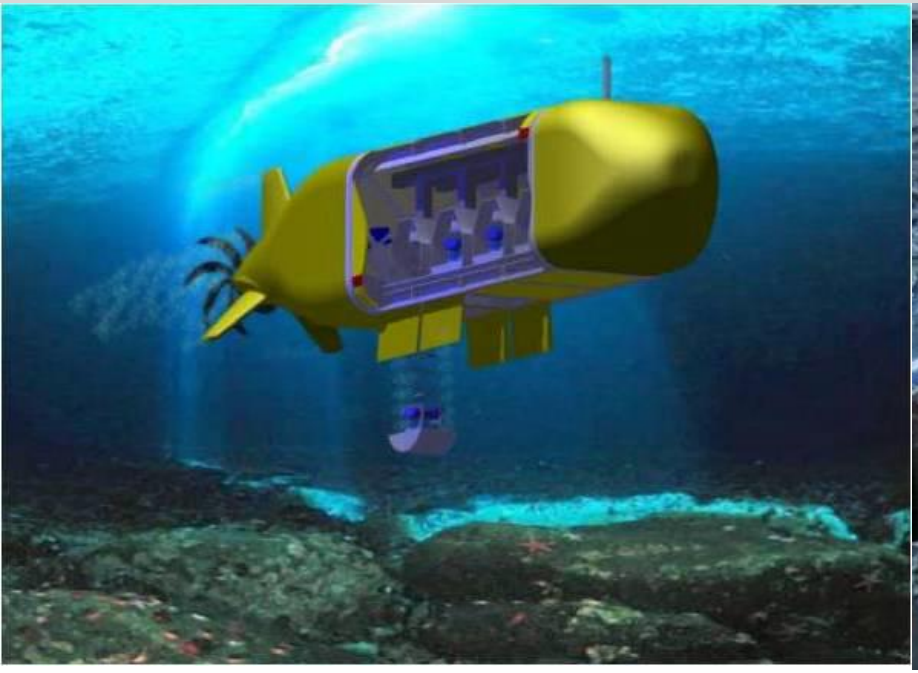
TELEDYNE
ENERGY SYSTEMS, INC.
A Teledyne Technologies Company

NASA

# OVERVIEW

Autonomous Underwater Vehicles (AUV's) have received increased attention in recent years as military and commercial users look for means to maintain a mobile and persistent presence in the undersea world. Teledyne Energy Systems, Inc. (TESI) is committed to meeting the energy needs for these missions



# BACKGROUND

TESI has been developing EDR (Ejector Driven Reactants) systems for air independent applications

## What's Important?

- Space – reliability, efficiency, and mass are priority
  - Power levels from 0.5 kW – 15 kW
  - Work closely with NASA
  - EDR systems have highest demonstrated TRL
- AUVs - reliability, efficiency, and volume are critical
  - Power levels from 0.5 kW to 70+ kW
  - Working with NASA JSC under SAA

# AUV REQUIREMENTS

Extended Mission Duration

- Mission lengths from 1 – 70 days needed depending on platform
- Battery systems cannot meet the requirement
- TESI LTPEM systems can meet these demands when paired with the appropriate reactant storage

Neutral Buoyancy/Closed Cycle

- TESI proprietary Integrated BOP system compactly captures and stores all byproducts onboard

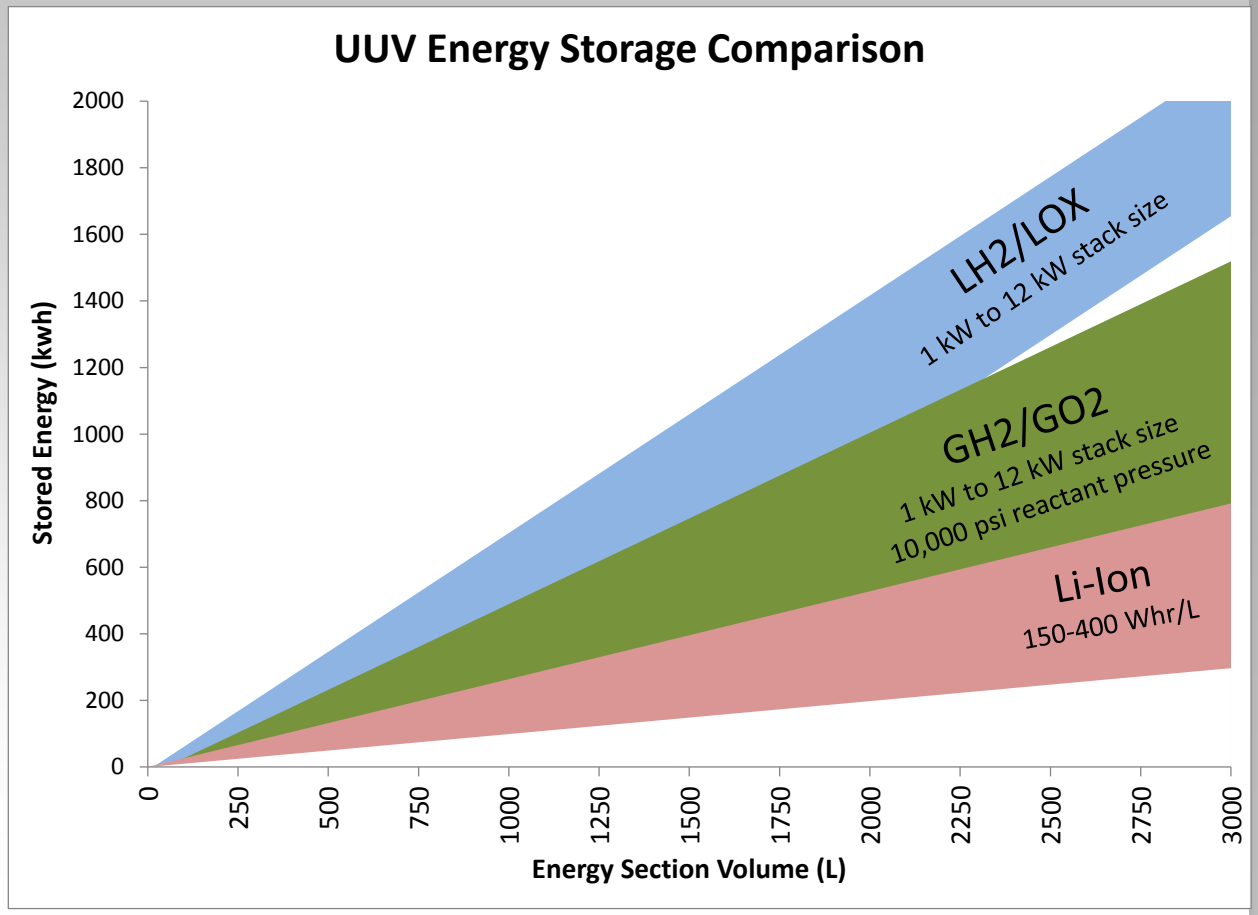
High Reliability

- TESI long history of air independent LTPEM FC systems development
- Use of high TRL technologies

# REACTANT (ENERGY) STORAGE

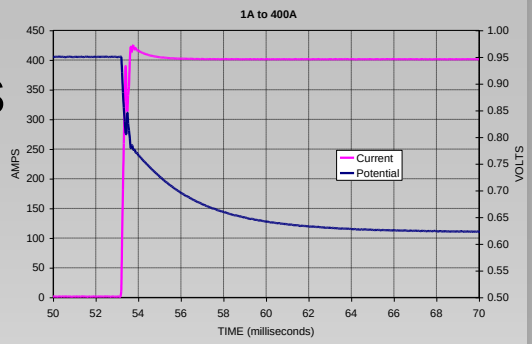
TESI trade studies indicate LH2 and LOX provide exceptional reactant system storage density

- Relatively high TRL
- Provides high purity reactant to FC system
- Can be refueled using water and electricity



# TESI LTPEM FC SYSTEM ADVANTAGES

- Load following
  - Able to respond quickly to load changes
  - FC stack responds in µs
  - Custom BOP sized to meet load profile




- High TRL
  - Demonstrated long life with H2/O2 reactants
  - EDR systems have proven reliability, used extensively in automotive FC systems
- Compact
  - Highly integrated subsystems
    - Water separation/reactant conditioning performed in FC
    - Reactant pressure and flow control integrated into the BOP endplate
    - Working with NASA JSC on advanced ejector technology

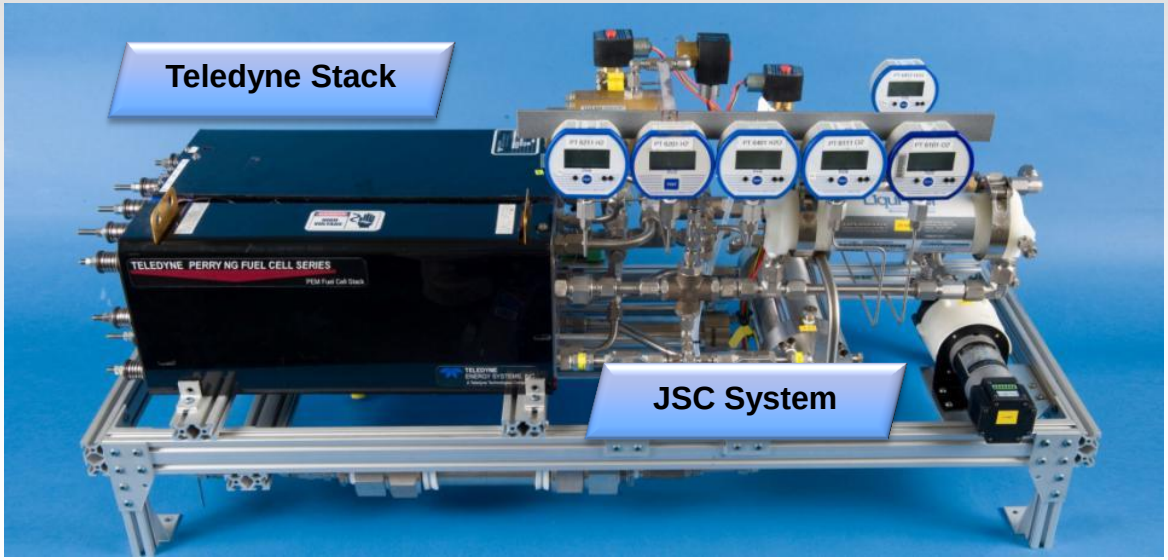
# NASA – TESI DEVELOPMENT UNDER SAA

NASA JSC

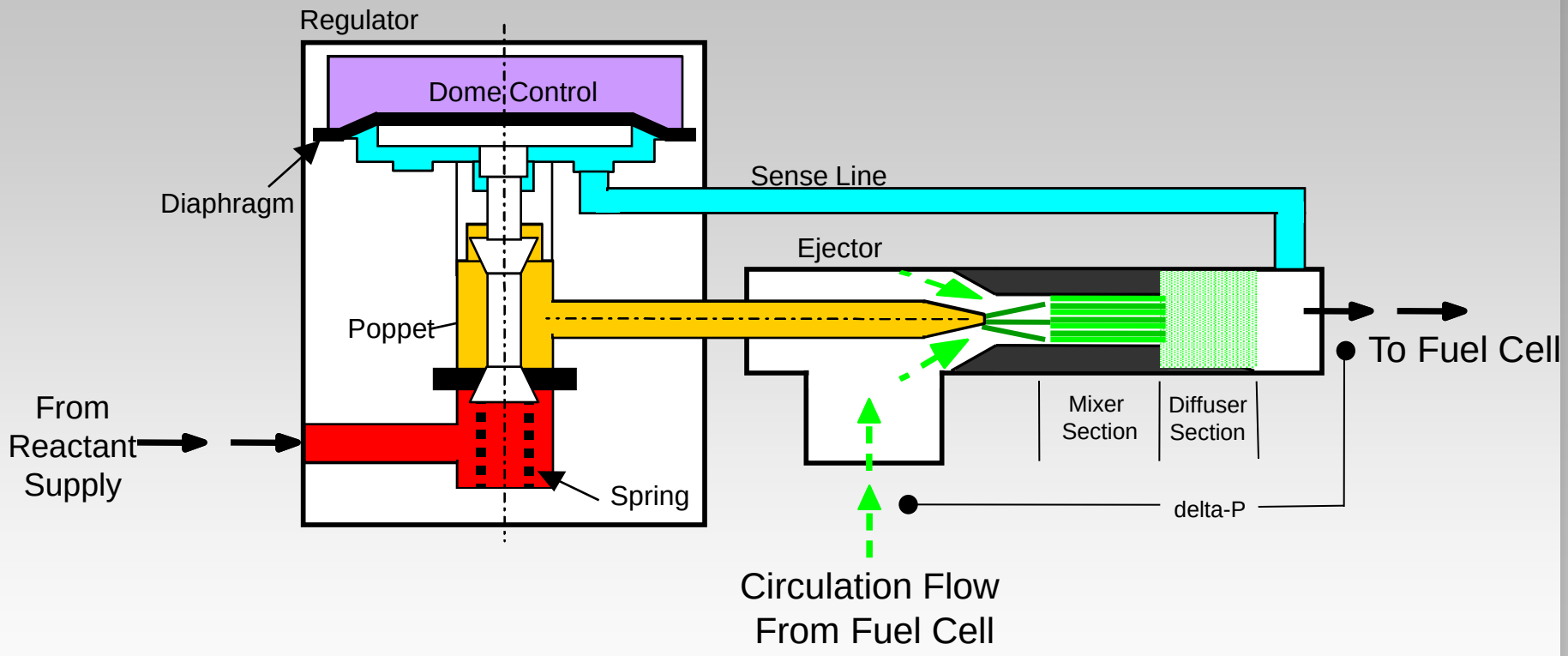
- Ejector – Regulator performance test data
- Design assistance during incorporation of pressure regulation/ejector into FC endplate

TESI

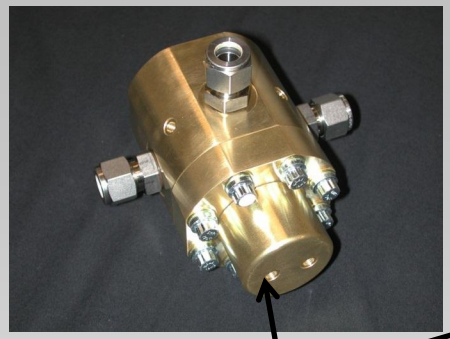
- BOP endplate design
- Design of planar reactant conditioning assemblies
- BOP endplate fabrication



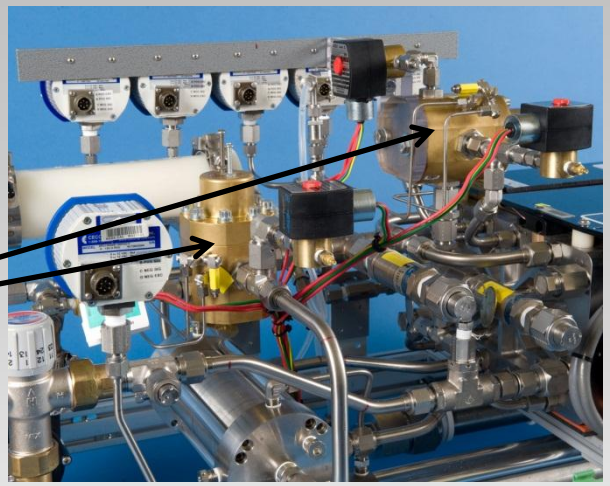
# NASA JSC DEVELOPED PASSIVE EJECTOR



# BOP/STACK INTEGRATION



Stand alone Ejector-Regulator developed by NASA JSC

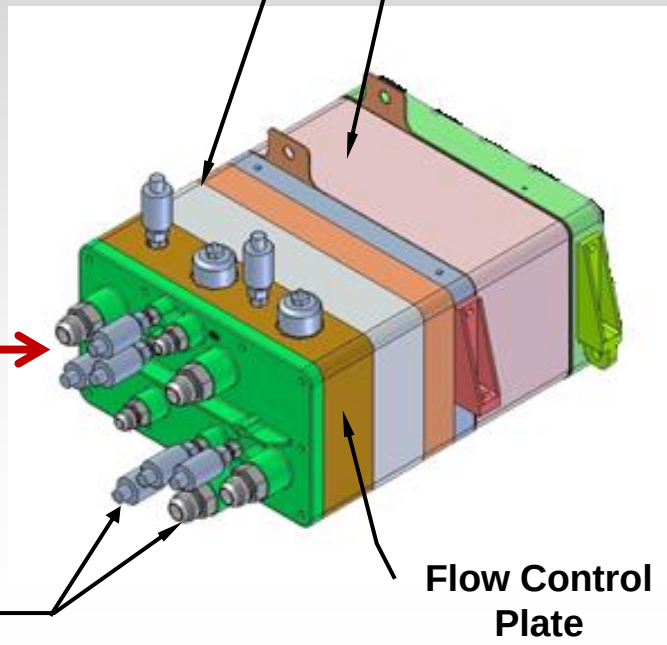


NASA JSC breadboard system

**Reactant Conditioning/H2O Separation**

**FC Stack**

**Integrated BOP/FC Concept**

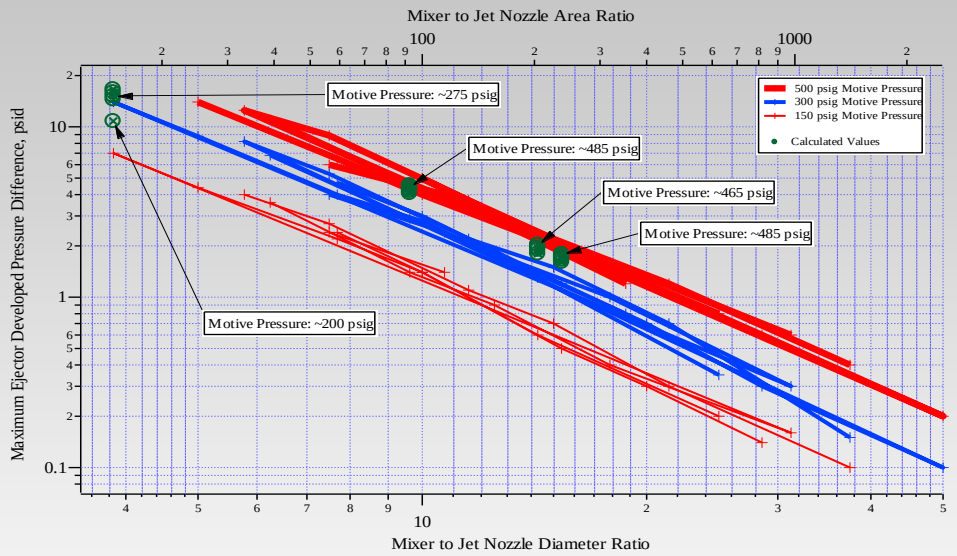


**Sensors and Valves**

**Flow Control Plate**

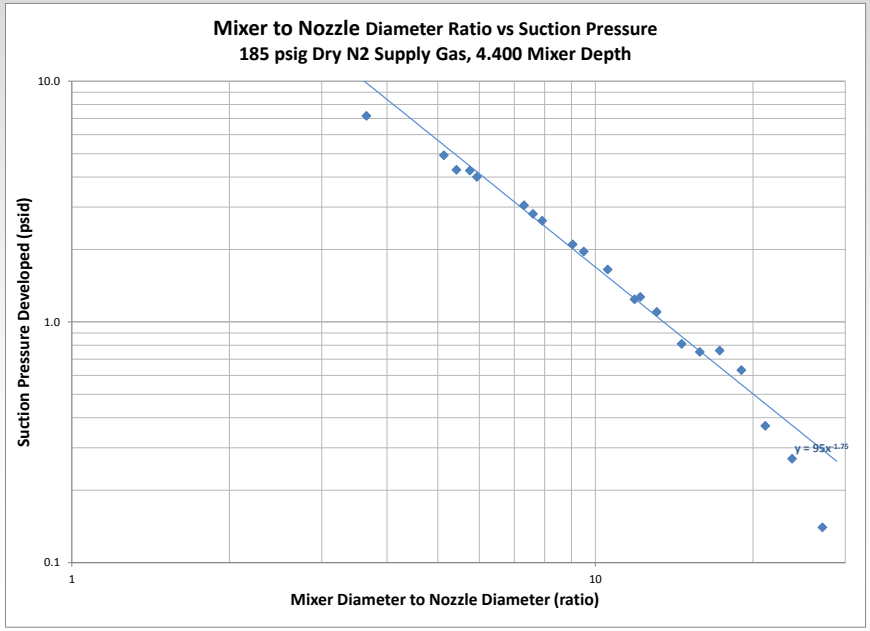
# EJECTOR VERIFICATION TESTING AT TELEDYNE

In-house test results of the stand alone hardware were similar to NASA's test measurements



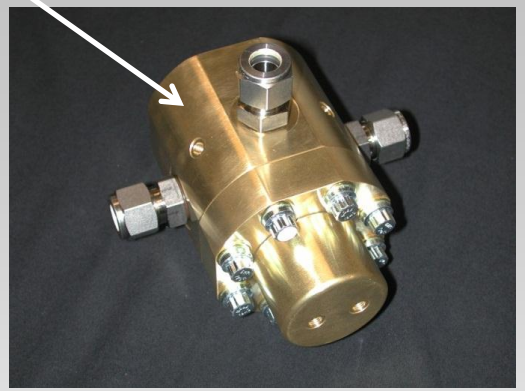

NASA JSC Data from 2010

TESI Data from 2012

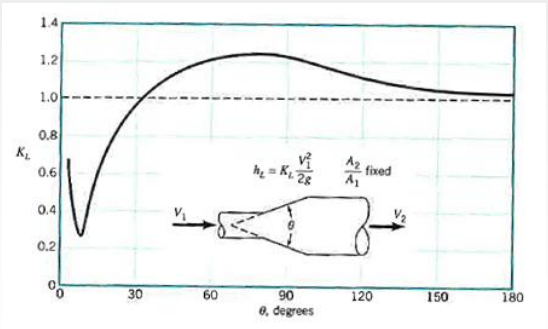


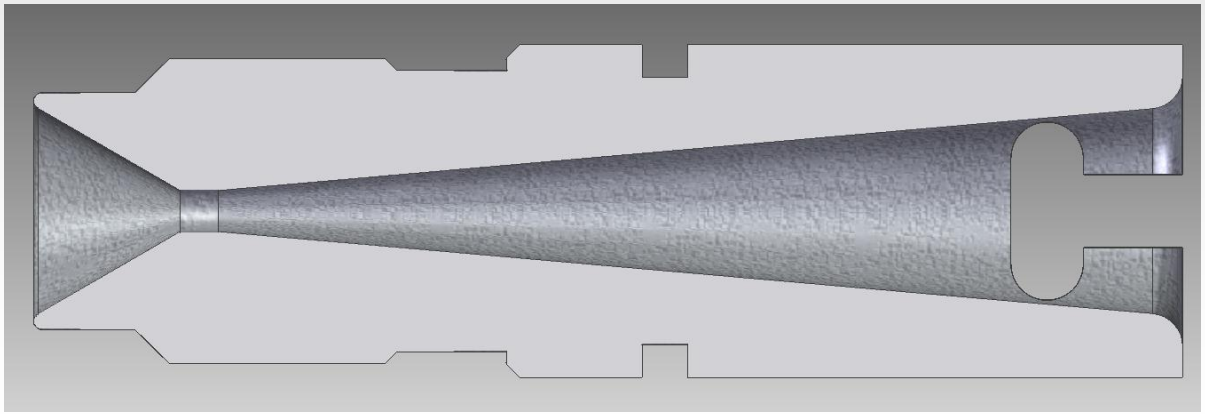
# EJECTOR OPTIMIZATION AT TELEDYNE

Stand alone ejector-regulator was limited to a constant volume mixer section



- A diverging taper angle was added, the taper is a little greater than ideal, but reduces manufacturing costs
- Features needed to be added to facilitate mixer installation, removal, and depth adjustment

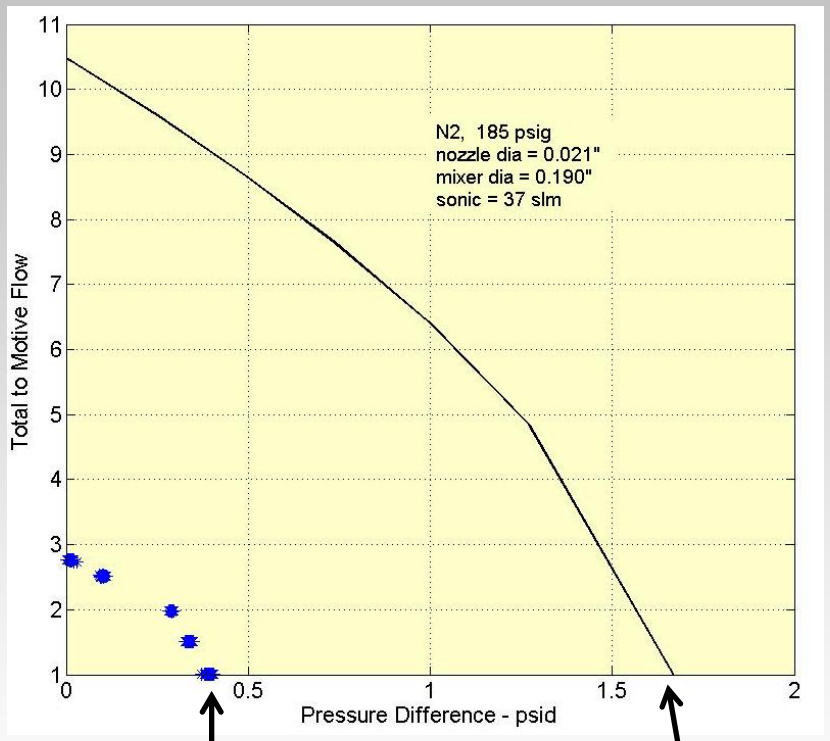


# EJECTOR TESTING AT TELEDYNE

## Comparison of losses developed by new and old mixers

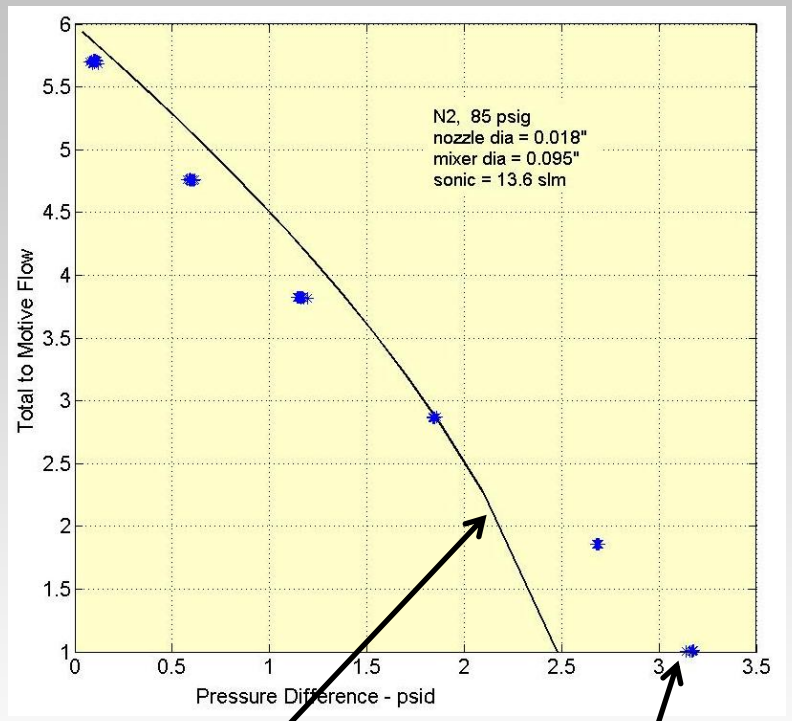
Old Mixer




Actual Performance
(Constant Area Mixer)

Theoretical Performance
(Constant Area Mixer)

New Mixer

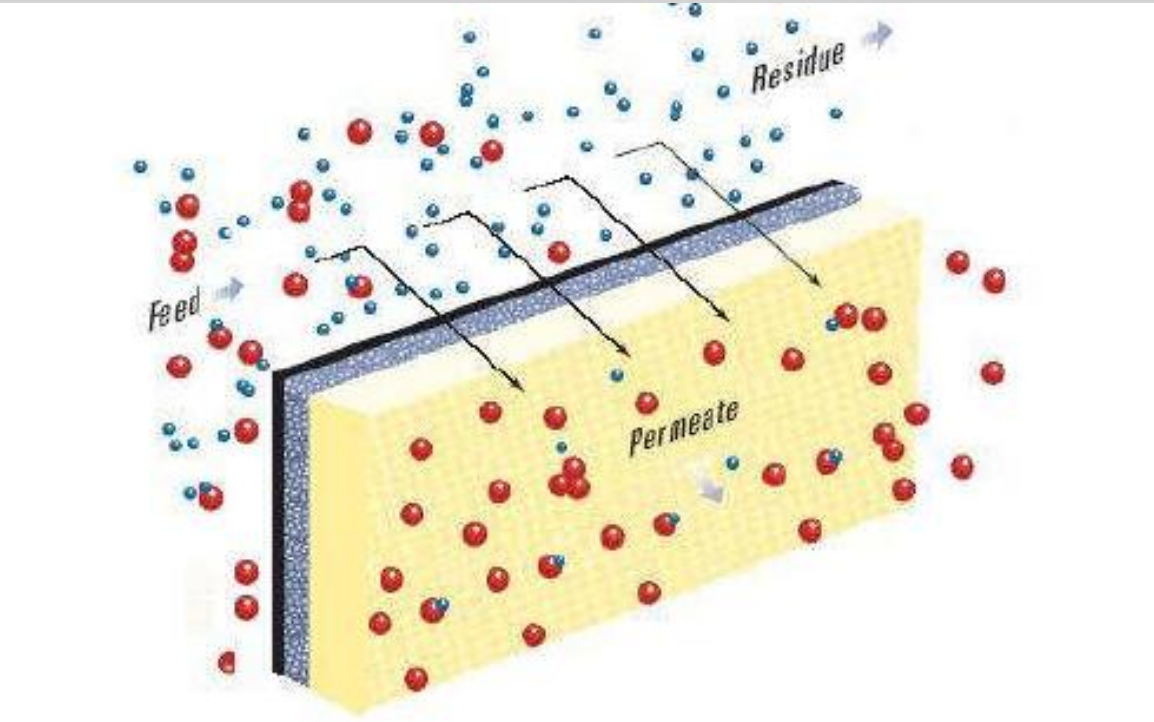



Theoretical Performance
(Constant Area Mixer)

Actual Performance
(Venturi Mixer)

# PASSIVE PLANAR WATER SEPARATION THEORY

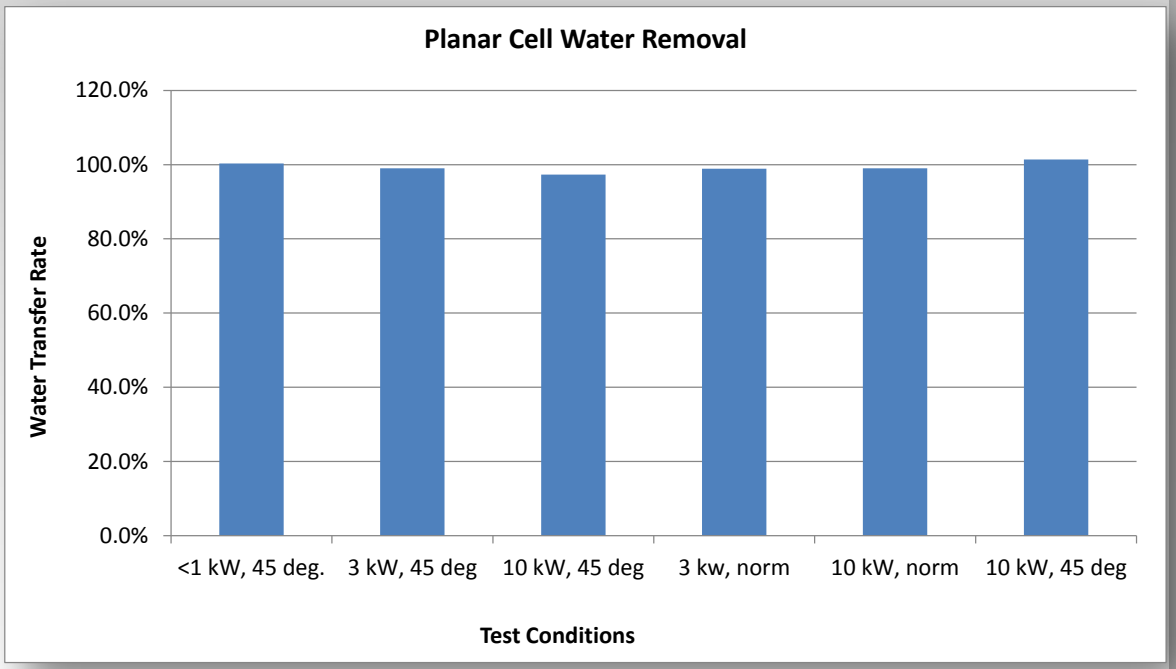
TESI planar separators completely remove liquid water from the reactants exiting the FC stack by incorporating a hydrophilic water separation membrane.



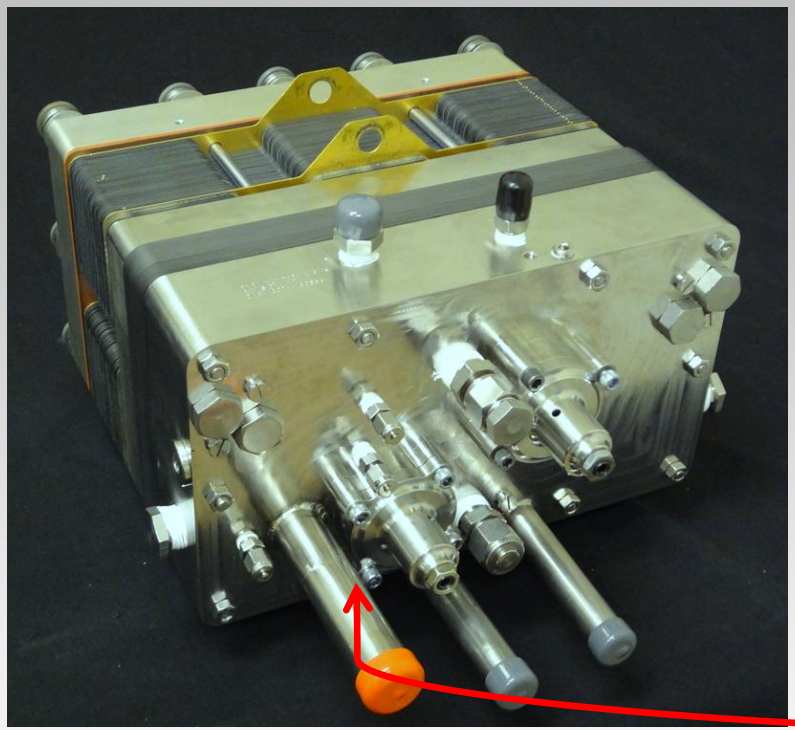
# PASSIVE PLANAR WATER SEPARATION

## Advantages of planar water separation

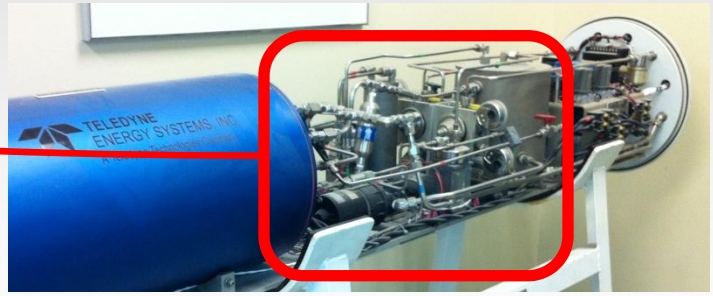
- Less volume - incorporated into the FC stack
- Thermal advantage - controlled temperature to maintain desired dew point
- Gravity independent – can be configured for zero G or changing orientations in 1G (pitch and roll)
- Testing has confirmed complete separation up to 10 kWe

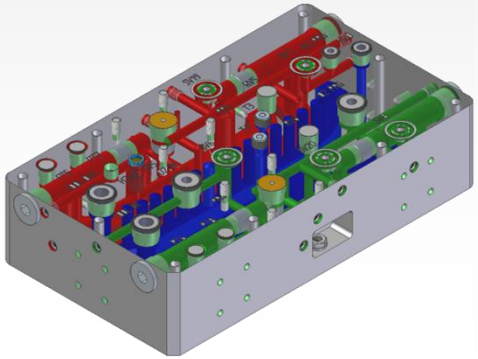


# COMPACT FUEL CELL BALANCE OF PLANT

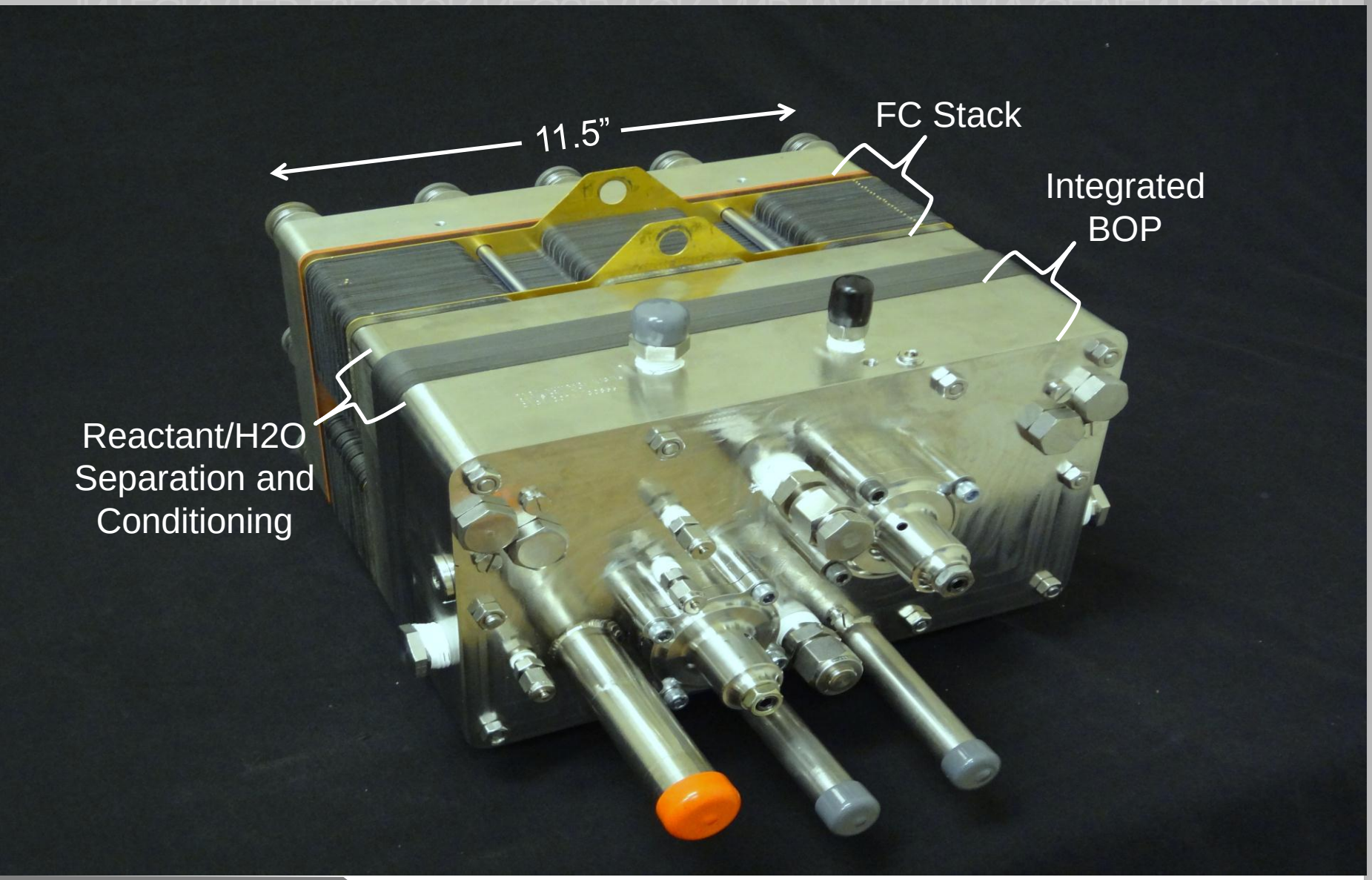


- Integrated BOP provides a compact package for the ejectors, instrumentation, controls, and flow paths.
- Internal manifold design provides a much more compact BOP compared to traditional BOP layout



# INTEGRATED EJECTOR-REGULATOR AND WATER MANAGEMENT SYSTEM



# CONCLUSIONS, FUTURE WORK

- Compact Ejector based systems have been demonstrated by TESI and NASA in a number of system configurations
- Planar water separation and conditioning has been tested in ex-situ test beds and breadboard demonstrations with equivalent H2O production rates up to 10 kWe
- Fully integrated systems will be demonstrated early in 2014
- Additional IR&D spending on advanced variable orifice ejectors is planned for 2014