




# NUVERA<sup>®</sup> Fuel Cells for Off-Road Equipment What Matters?

Gus Block, Director of Corporate Development

An aerial photograph of a construction site. A yellow excavator is positioned on the left, and a yellow truck is on the right. The ground is dark and uneven, with visible tire tracks. The scene is dimly lit, suggesting dusk or dawn.

## Off-road equipment operators face significant emission reduction requirements

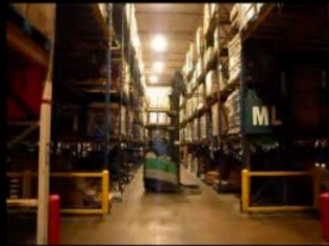
Offering compliant machinery can involve years of planning and development

### Critical requirements include:

- Evaluating new propulsion technologies that match equipment operational requirements
- Identifying the most promising options for the application
- Meeting code requirements
- Testing
- Validating reliability
- Establishing manufacturing and service capability
- Providing acceptable cost of ownership

# 25+ YEARS OF FUEL CELL MOTIVE POWER

Operational projects and vehicles in a variety of applications



# Versatile Applications



**Hyster® Top Loading Container Handler**  
**Nuvera Fuel Cell Engine Configuration**  
**90 kW Total Power**

*The new 52-ton capacity Hyster® laden container handling electric truck is currently located at the Company's testing facility in Weeze, Germany. This truck, powered by a hybrid system that utilizes both a lithium-ion battery and fuel-cell engine, awaits shipment to the Port of Los Angeles to begin its testing phase.*

# DD DANNAR Power to Transform



## DANNAR® Mobile Power Station

Electric platform addressing diverse off-road applications



*There is significant unmet need for zero-emission energy solutions for high-performing vehicles and work machinery, especially where **access to the grid is limited or non-existent** and where diesel emissions are unacceptable.*

*With Nuvera's capabilities to provide **ruggedized fuel cell power systems** in applications that must sustain adverse environmental conditions and require long run-time, our Mobile Power Stations will have the ability to **transform diverse markets with high-performance zero-emission options.***

Gary Danner, Founder and CEO of DD DANNAR.

# Nuverera<sup>®</sup> E-Series Fuel Cell Engine



## Unique Patented Controls

*Optimized performance, self-protection, and maintenance of water balance under dynamic operating conditions*



## Compact Compressor

*Fully integrated and low parasitic power*



**Hydrogen Ejector**  
*100% passive fuel recirculation without power loss*

## Nuverera<sup>®</sup> 8<sup>th</sup> Generation Fuel Cell Stack



## Open Flow Field

*Increased efficiency and power density*

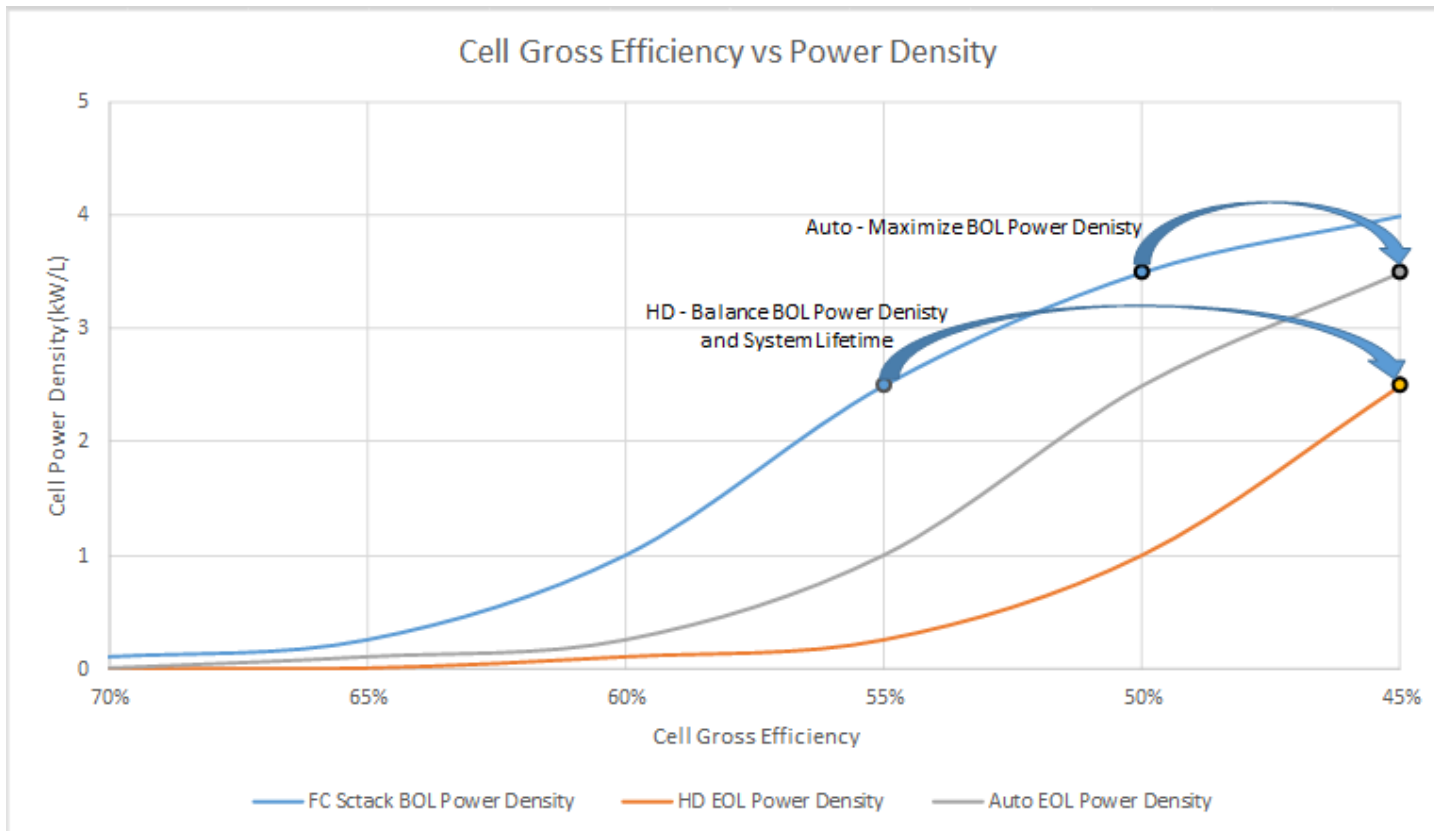


## Metal Plates

*Superior resistance to shock and vibration*

# E-Series Engine

Balancing Power Density, Efficiency, and Lifetime



Notes:

- NFC E-Series cell power density shown
- EOL conditions based on 45% efficiency (~550mV/Cell) - actual drive conditions and vehicle thermal management system will determine in service lifetime

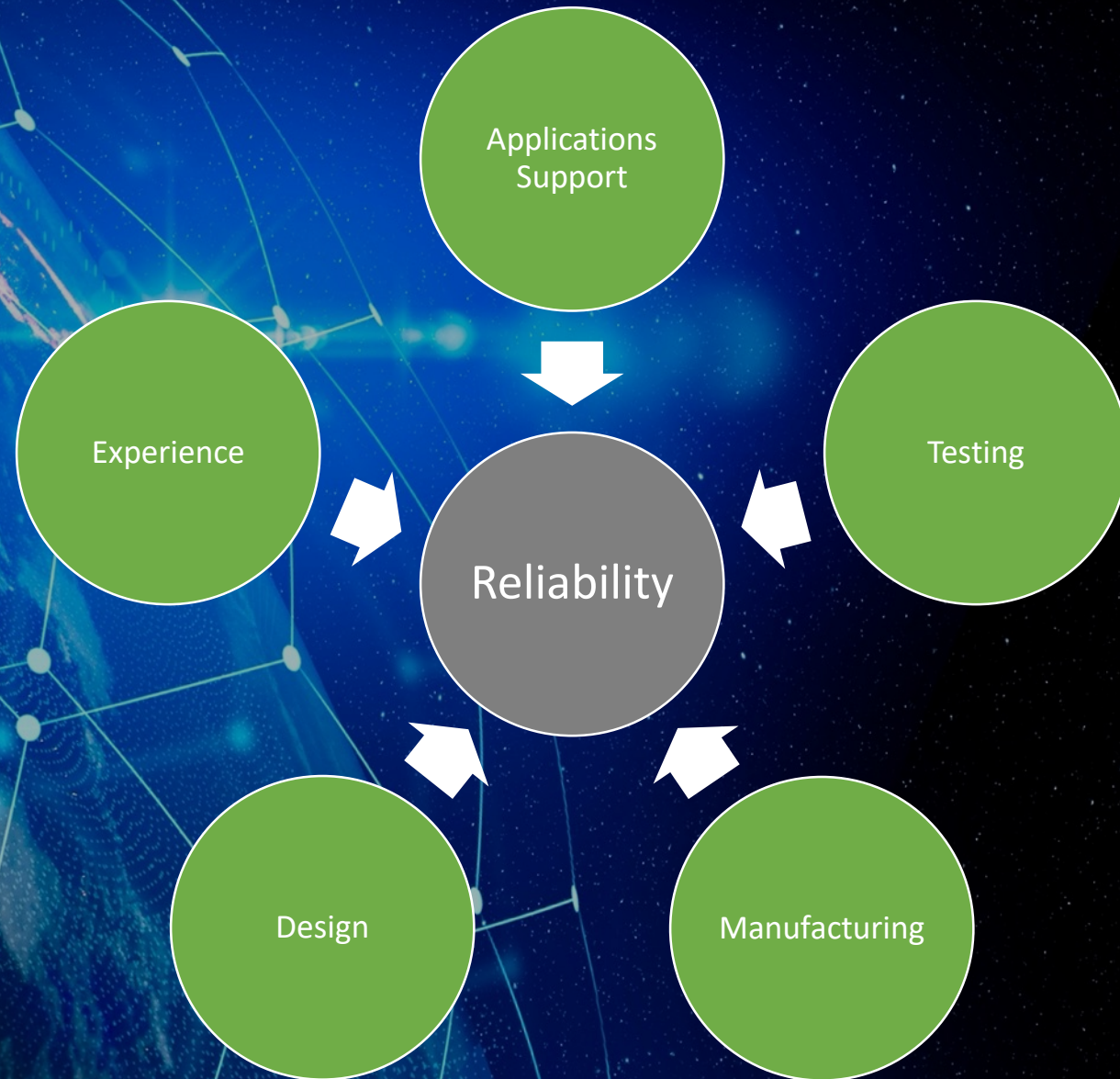


## Nuvera E Series Engine

- + **High Reliability** to keep equipment up and running
- + **Durability** for lower cost operation
- + **Ease of Integration** to quickly move from concept to production

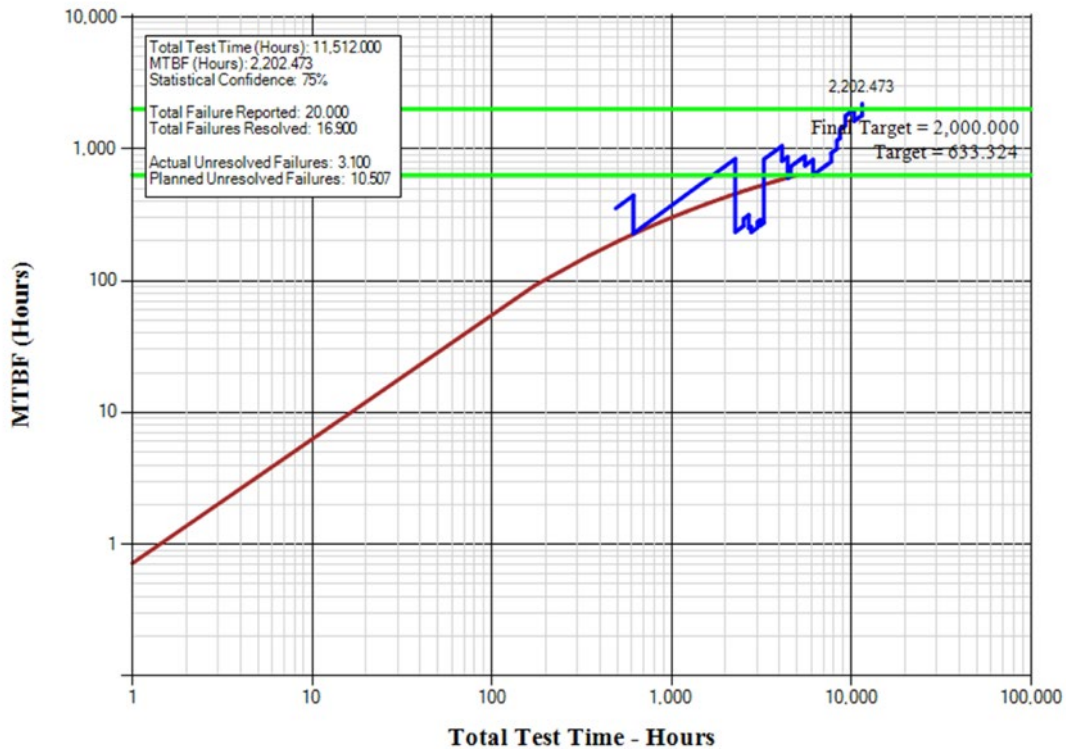


# What Matters: RELIABILITY



# E-Series Engine

## Reliability Testing



- + **Phase 1 testing** - Early stage testing on engineering units to provide rapid feedback on early failures
  - + Target >2000 hours MTBF demonstrated
- + **Phase 2 testing** - Larger scale testing in process on production engines to provide improved statistics for MTBF.
  - + Production processes, components, and controls updated based on corrective actions developed
  - + Engine lifetime confirmed at system level based on test profile – combination of both urban and highway drive cycles
- + **Reliability (MTBF) and durability** (stack lifetime hours) used to evaluate application cost of ownership



# What Matters: Manufacturing Capability

# Automated Manufacturing & Testing

- + Low-cost / high-volume manufacturing capability
- + High quality assurance
- + Manufacturing processes developed at Nuvera headquarters for duplication at other plants
- + Expandable production capacity build-up based on Demand Flow Technology Platform



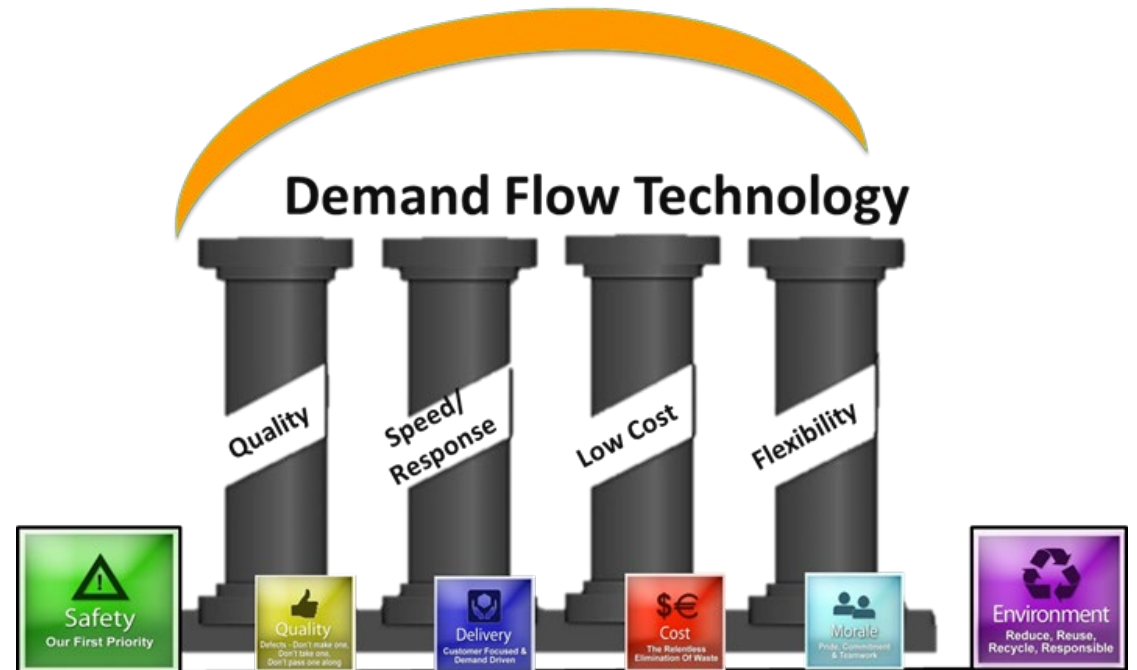
— **Certified**

ISO 9001-2015

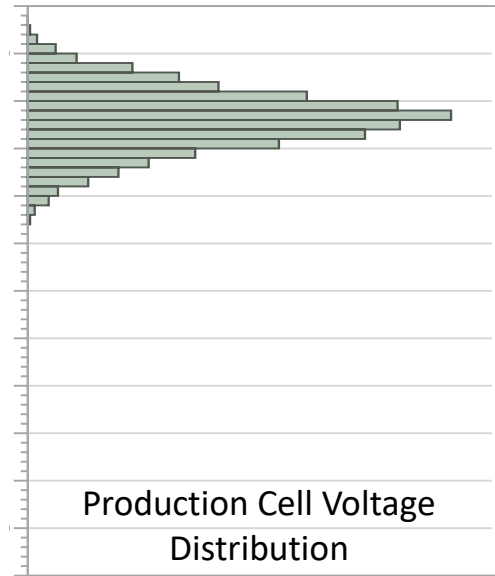
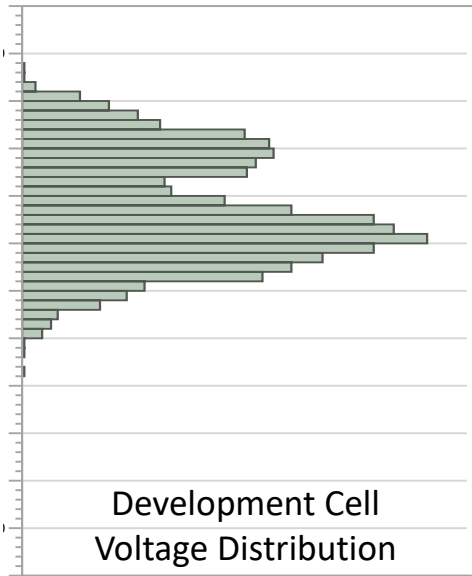
ISO 14001-2015

OHSAS 18001

Nuvera Fuel Cells, LLC, Billerica, USA



# Automated Manufacturing & Testing



- + Manufacturing improvements stabilized and improved cell voltage distribution within large stacks
- + 10mV of BOL voltage ~ 1600 hours additional stack life





# What Matters: Ease of Integration

# Fuel Cell Engine Layout

**Embedded Controller**  
Simplified vehicle integration and engine operation

**Air Compressor**  
Fully integrated. No additional sourcing, packaging, or cost.

**Coolant Pump**  
Fully integrated. No additional sourcing, packaging, or cost.

**Power Out (+)**

**Vibration Isolation**

**Air Supply**

**Power Out (-)**

**FC Stack**

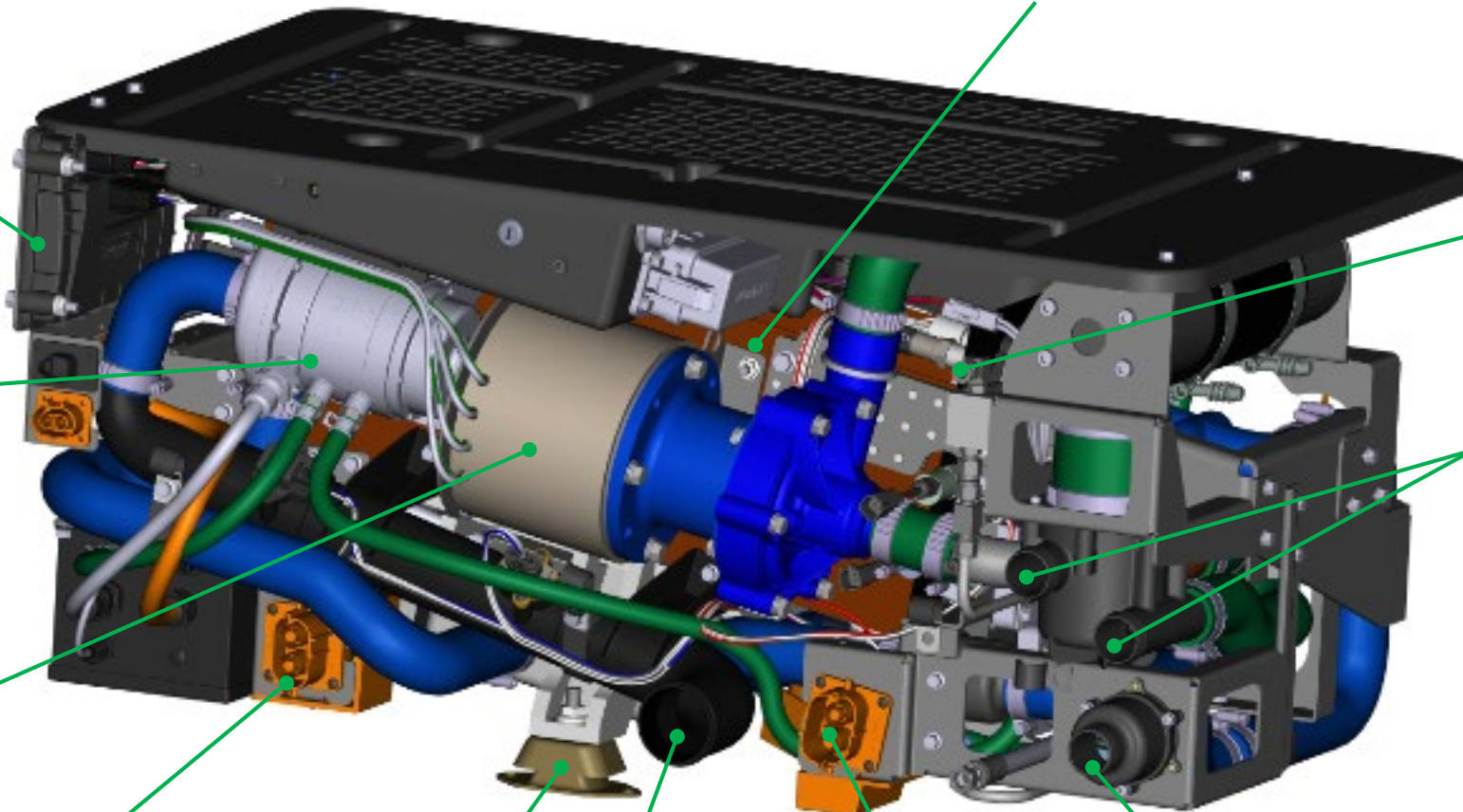
**Compact Nuvera® Fuel Cell Stack** provides high efficiency

**Hydrogen Supply**  
**Proprietary ejector** circulates hydrogen without electricity and further boosts efficiency

**Coolant Connections (Radiator)**

**Exhaust**

**Standardized inputs and outputs** simplify interconnection to vehicle powertrain



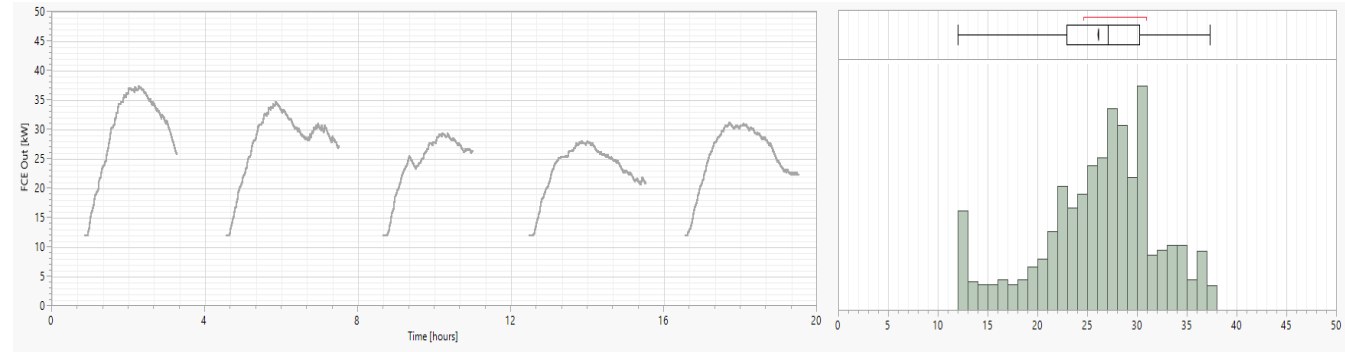


# What Matters: Total Cost of Ownership

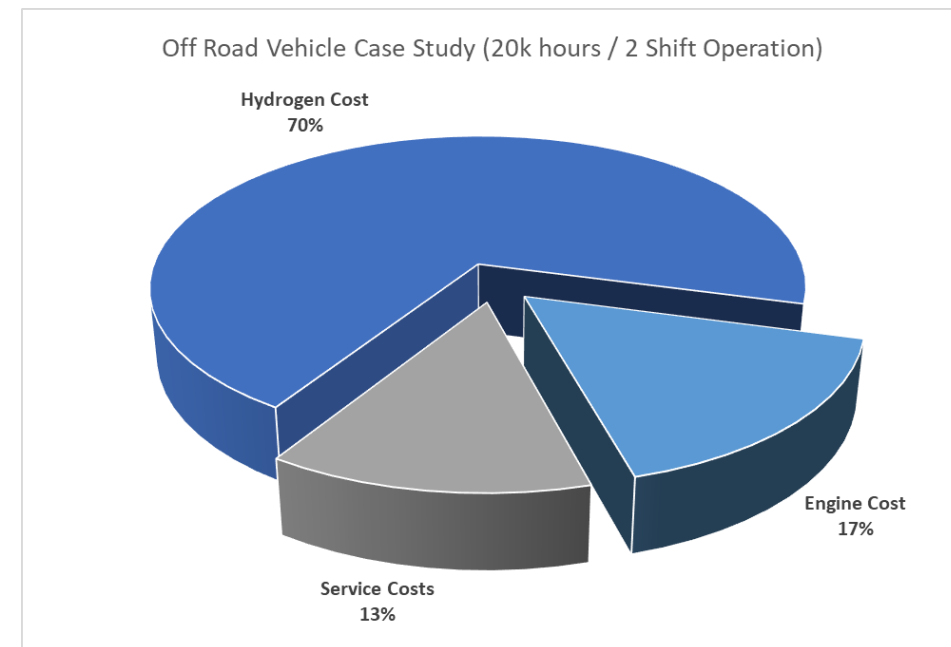


# E-Series Fuel Cell Engine Cost of Ownership

- + Application use profile critical to understand actual lifetime in real world applications
- + Calculate cost of ownership for fuel cell engine
  - + Upfront cost of fuel cell engine (\$/kW)
  - + Minimum power requirements for application to not see decreased performance
  - + Durability profile of fuel cell engine (power output reduction vs time)
  - + Hydrogen usage over life of vehicle as fuel cell engine efficiency changes over time
  - + Service and Preventive Maintenance Requirements



**Example Fuel Cell Power Requirements – 2 Shift/Day Off Road Application**



# High-performing off-road vehicle and work machinery start with:

- Application assessment
- Simulations and analyses
- System module compatibility reviews
- Controls interface experiments
- Load modelling
- Component selection and configuration



# Nuvera Applications Development and Customer Solutions

*Experienced and highly responsive global customer application engineering and customer solutions teams*

## Customer Access and Product Influence

- + Participates in customers' product design reviews and planning
- + Provides customers access to decades of knowledge resulting in continued hydrogen and fuel cell innovation

## Documentation and Training

- + Tailor-made customer-facing integration documentation
- + Customized training material and presentation
- + Product manuals

## Matching State-of-the-Art Products with Knowledge and Expertise

- + Highly-trained global support team
- + Remote and on-site support
- + Direct service and aftermarket support

# WHAT MATTERS

## Nuvera's approach to harness the power of fuel cells

- 25+ years of motive power experience
- Unique fuel cell technology
- Automated manufacturing and quality assurance
- Applications assessment and analysis
- Comprehensive integration support



# NUVERA<sup>®</sup>



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