High Efficiency Fuel Cell Application for Medium Duty Truck Vocations

Stan Bower – Principal Investigator
Ford Motor Company

Project ID: TA057
Award: DE-EE0009858

June 2023

Project Goal

- Develop a ZEV Fuel Cell propulsion system for Ford Super Duty Chassis Cab vocation applications.
- Demonstrate ZEV capability without compromised customer attributes including 10k payload, 300-mile range and SAEJ2601 refueling times.
- Evaluate the technology in real-world environments with three fleet customers (varied vocations and locations) to provide insight into fuel cell durability, usage, efficiency, refueling, and operating costs.
- Evaluate GHG and TCO utilizing H2 infrastructure and economy projections for comparison with today's ICE products.

Super Duty Chassis Cab ZEV Fuel Cell

Overview

Timeline

Project Start: Mar-2022
Project End: Dec-2026
Complete: ~20%

Budget

Total Project Budget: $49.9M

Cost Share: 50%
DOE Funds Spent: $7.35M*
DOE Funds Received: $4.48M

**includes April 2023 estimate*

Barriers and Challenges

- H2 Infrastructure and cost
- Commercial vehicle lifetime durability
- Capability in extreme cold environments

Partners and Fleet Customers

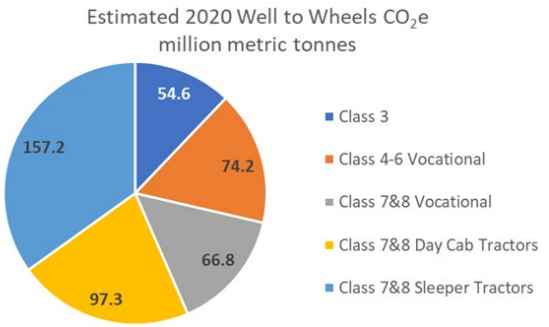
Ford, FEV, NREL Transforming ENERGY, Consumers Energy Count on Us®, FERGUSON, SoCalGas

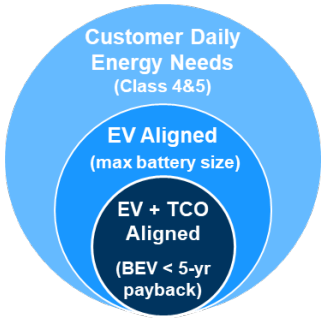
~$50M / Two Partners / Three Customers

Any proposed future work is subject to change based on funding levels

Relevance and Potential Impact

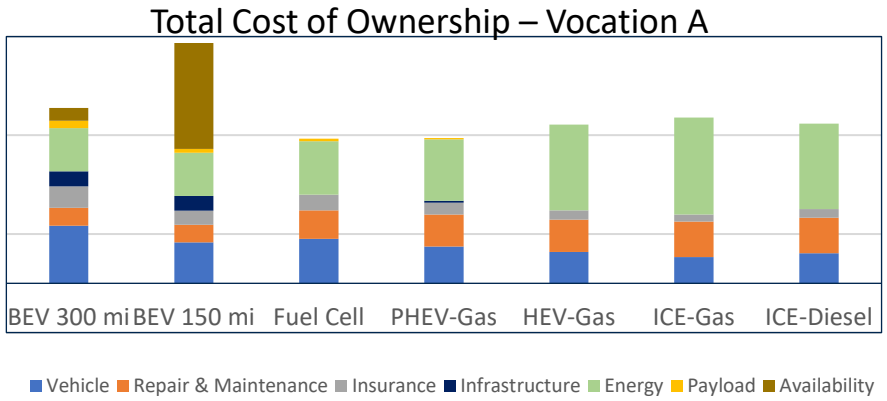
- **The vocational CV market is a smaller but still significant portion of the CV CO2/GHG contributions but presents unique decarbonization challenges.**
  - Work trucks operate in rugged environments, with high payload demands and in some cases 24/7 uptime requirements.
  - BEV's are challenged to meet the energy demands (>300 kWh) and/or uptime requirements.
  - The class 3-6 Chassis Cab vocational market is especially important to Ford as a leader in this segment.





- **Fuel Cell powertrain offers favorable attributes**
  - Zero emissions
  - Minimal payload compromise and re-fill time similar to ICE
  - Favorable TCO (amortizing down time) for high energy users

- **Overall Goals**
  - Achieve 300 mile range and maintain customer payload
  - Meet high energy daily usage / full capability in hot and cold ambient
  - Off-road capable / steep grade capable
  - Meet or exceed gas ICE TCO



- Availability represents cost of lost revenue from charge time
- 150-mile BEV is significantly impacted by charge time for high energy user

Medium Duty Vocation Applications are important to Ford and challenging for BEV.
Fuel Cell is the better ZEV solution for "work trucks"

Approach: Focus Areas per Phase

2022/2023 - Phase 1
Simulation/Analysis/Design

Virtual Design and Analysis (NREL)
Use Cases, Application and Infrastructure Modeling
System Sizing and Simulation

Component Development

2023/2024 - Phase 2
Vehicle Integration/Build

Fuel Cell Technology (FEV)
Cell Stacks, Balance of Plant
Thermal, H2 Storage, Controls

Electrification Technology
Battery, HV EDS/Power Electronics
Thermal, eAxle, Brakes, Steering, Controls

Development Vehicles

2024/2025 - Phase 3
Vehicle Development

Propulsion System and Vehicle Integration (FEV)
Integration, Build, Controls, Calibration
DV, Human Machine Interface, FuSa

Fleet Vehicles Deployed

2025/2026 - Phase 4
Pilot Vehicles

Fleet Vehicles (SoCalGas, Ferguson, Consumers Energy)
H2 Infrastructure, Real World Validation
Model validation and future scenario projections, Lessons learned for scaling

Go / No Go Criteria

Analytical Confirmation - System will achieve FC net power, net vehicle power, efficiency improvements relative to gasoline ICE, range and payload/towing requirements

Bench Testing and Builds - Internal development builds and FC net power bench validation complete

Vehicle Validation / Deployment – Customer requirements and vehicle attributes confirmed: 75% tank-to-wheel efficiency improvement, 300 mile range, 700 bar tank package, SAE J2601 fill time, and 10k payload

Development Areas and Support

Any proposed future work is subject to change based on funding levels

Accomplishments and Progress

Analytical Concept Evaluation – System Sizing

FCEV Super Duty F550 Chassis Cab

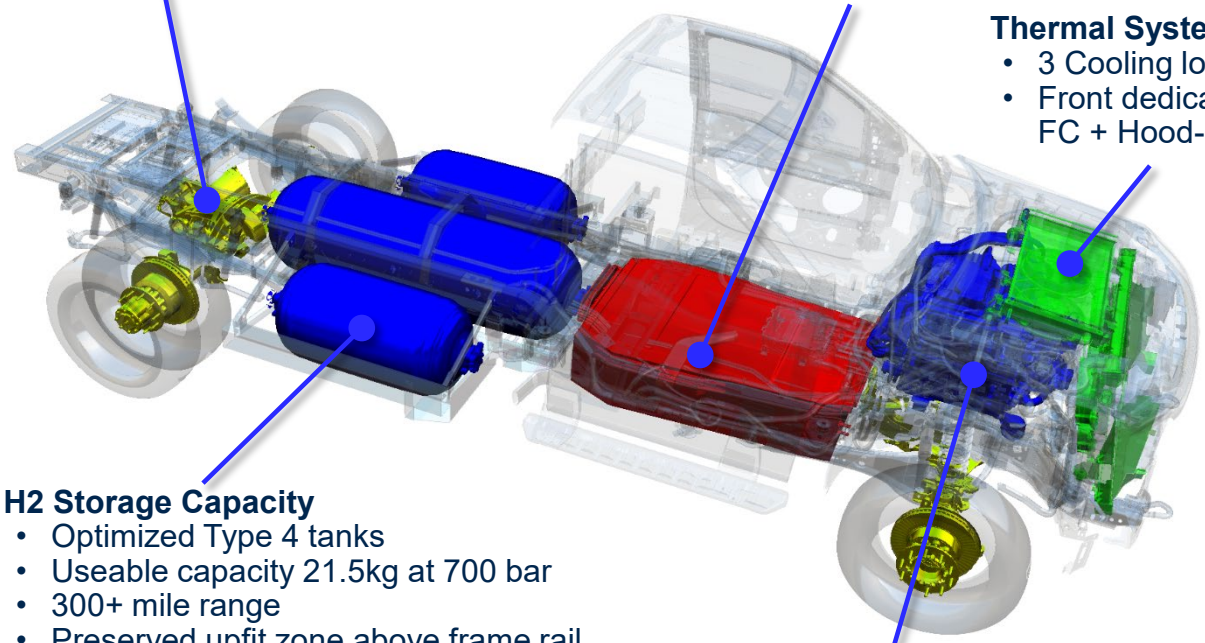
Pilot Attribute Priorities

- Performance equivalent to 7.3L gasoline P/T
- 10,000 lb payload / 20,000 lb towing capacity
- Meet or exceed 7.3L gas performance feel and launch capability
- 300+ mile range in shorter wheelbase variant
- Segment-comparable off-road capability
- Comparable refueling time (<10 minutes)
- Minimal upfitter zone reduction
- Comparable cold climate starting capability

Twin eAxles
- 300kW peak / 200kW continuous power (each)
- 13,000Nm Peak wheel torque (each)

HV Battery
- 350kW peak power
- Transient fill-in for slower fuel cell response
- 40kWHr usable energy for >140kW power demand

Thermal System
- 3 Cooling loops
- Front dedicated HTR for FC + Hood-mounted LTR



H2 Storage Capacity
- Optimized Type 4 tanks
- Useable capacity 21.5kg at 700 bar
- 300+ mile range
- Preserved upfit zone above frame rail
- Sub 10-minute refueling

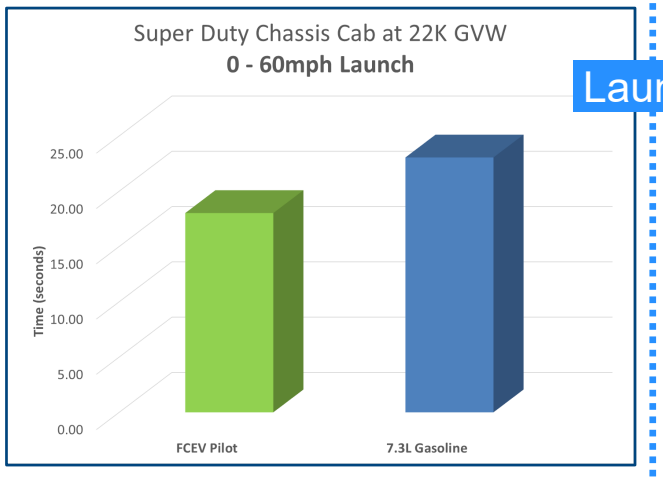
Fuel Cell System
- Optimized 2-row stack & BOP
- 140kW continuous power @38°C

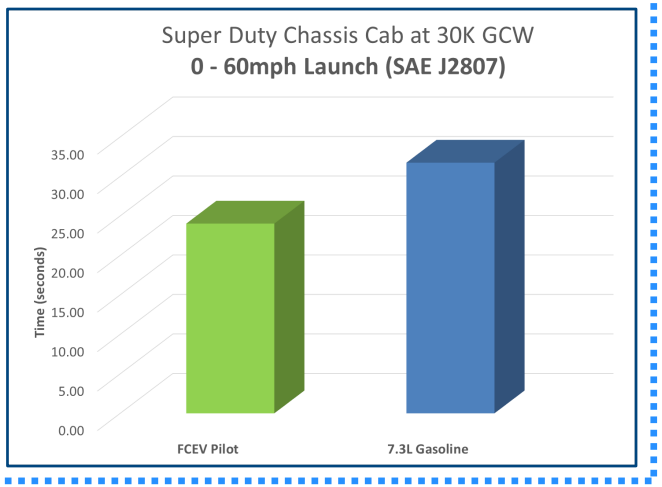
Super Duty FCEV Concept Sized for Comparable Performance to Current Ford 7.3L Gas

Accomplishments and Progress

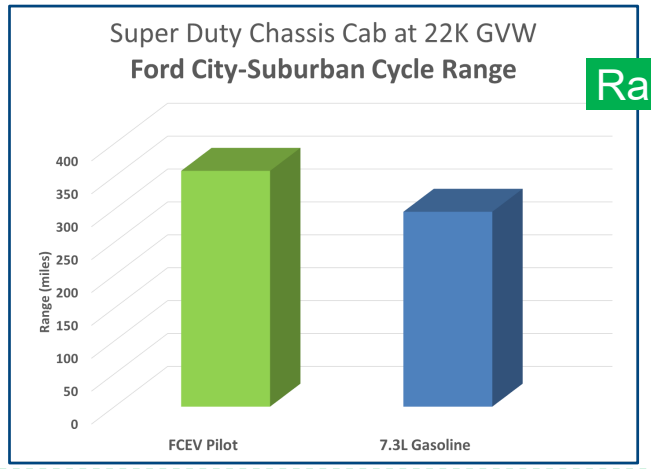
Analytical Concept Evaluation – Performance Attribute Analysis

Launch

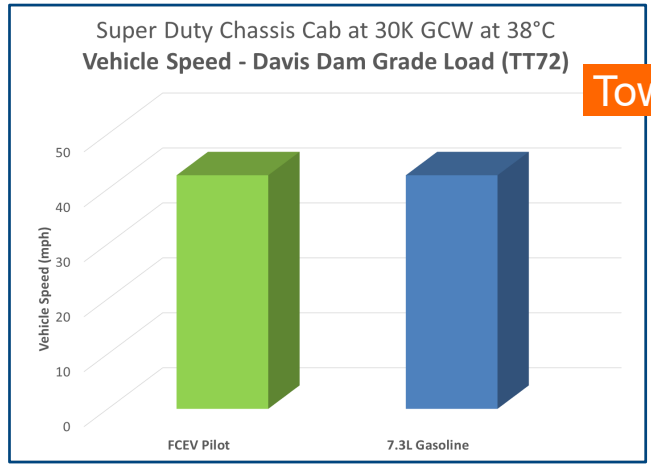




Range



Towing



GVW

GCW

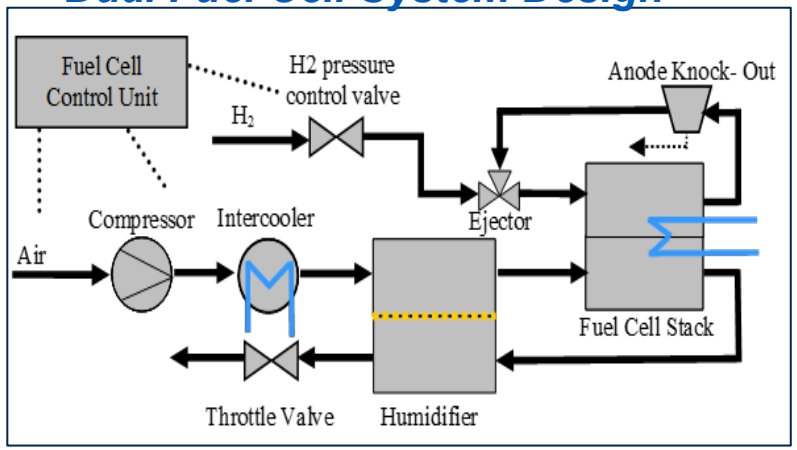
Launch Capability, Range, and Towing Capability from FCEV Vehicle Modeling

Any proposed future work is subject to change based on funding levels

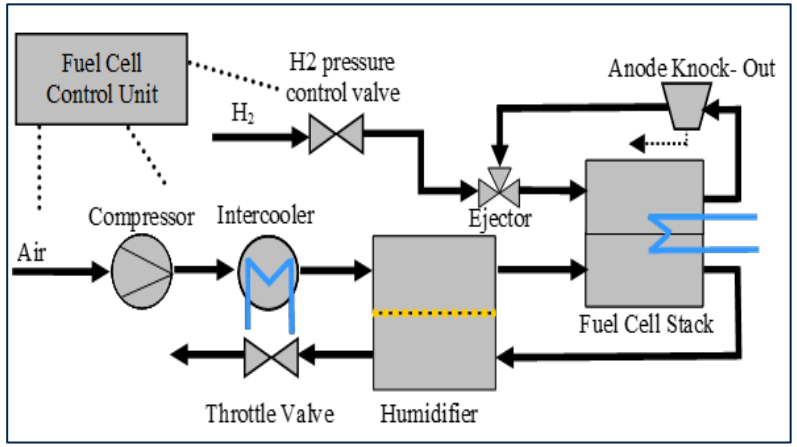
Accomplishments and Progress: Fuel Cell System

Typical Industry Medium-Duty (MD) Dual Fuel Cell System Design

System B



System A



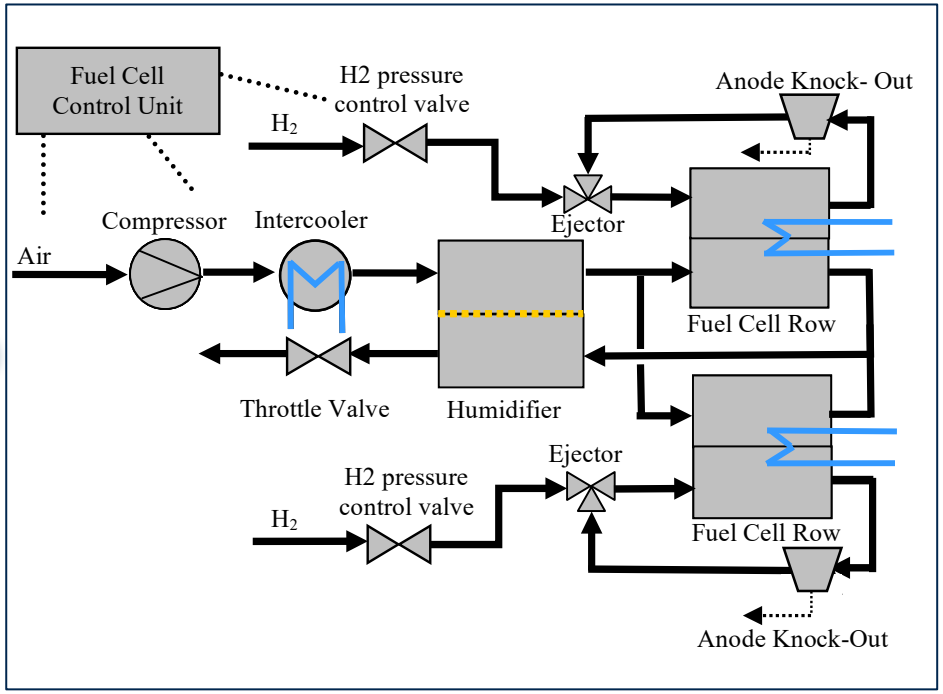
Ford System Design

- Single Cathode (Air) System
- Two Cell Rows
- Two Anode (H2) Systems

Concept Rationale

- 24% reduction in part count
- 20% reduction in system volume
- Resulting in cost reduction
- Production intent

Ford Fuel Cell System MD Design



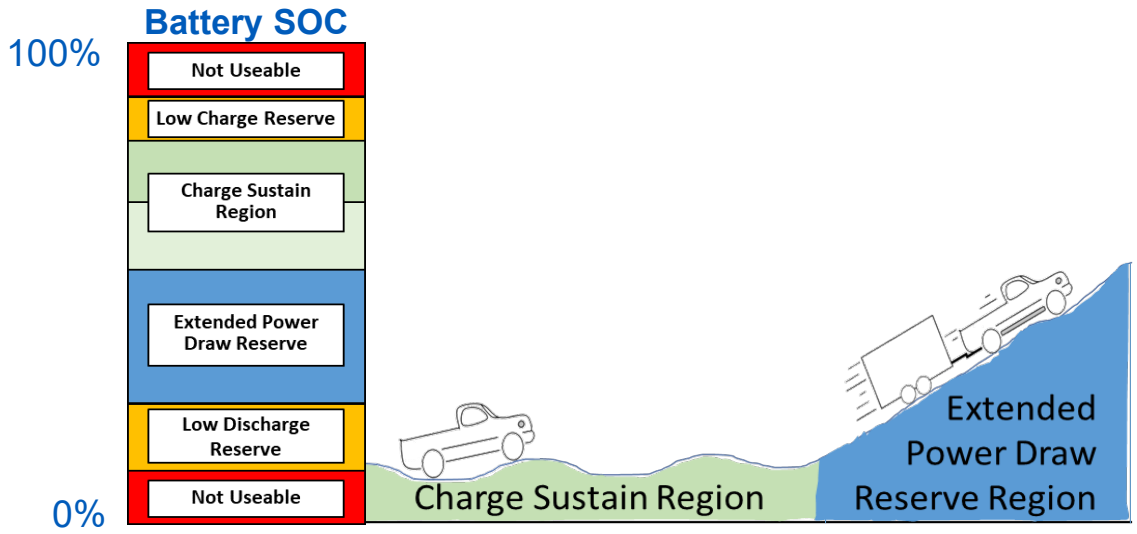
Schematic is a pictorial example of key components rather than a comprehensive representation of the system architecture

Ford Fuel Cell System Concept Is Integrated And Optimized For The MD Application

Accomplishments and Progress: Battery System

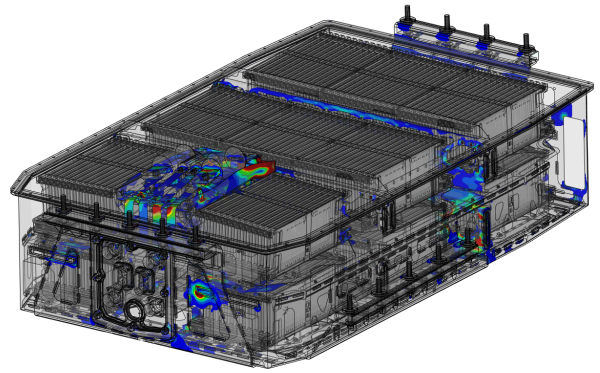
Battery Operating Requirements

- Supplement power during high load operation
- Absorb excess energy from fuel cell
- Supply full power during fuel cell start-up delay
- Hybridization strategy within charge sustain region being developed to reduce fuel cell system stressors



Battery pack has completed design freeze

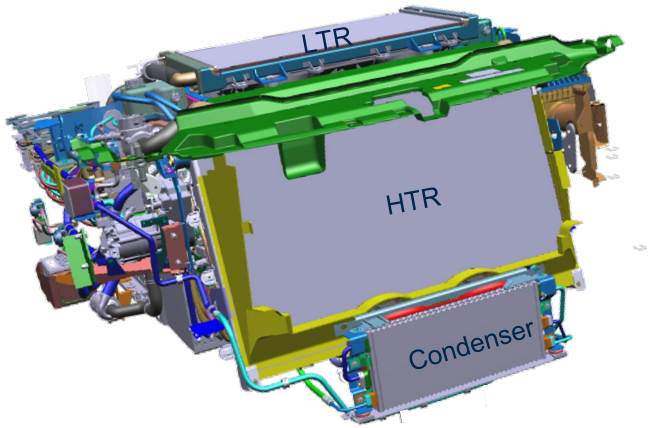
- Vehicle packaging, interfaces and voltage requirements
- Subcomponent fabrication in-process
- Functional development bench complete to support cell calibration and software development



Battery operating modes and energy reserves are critical for FCEVs

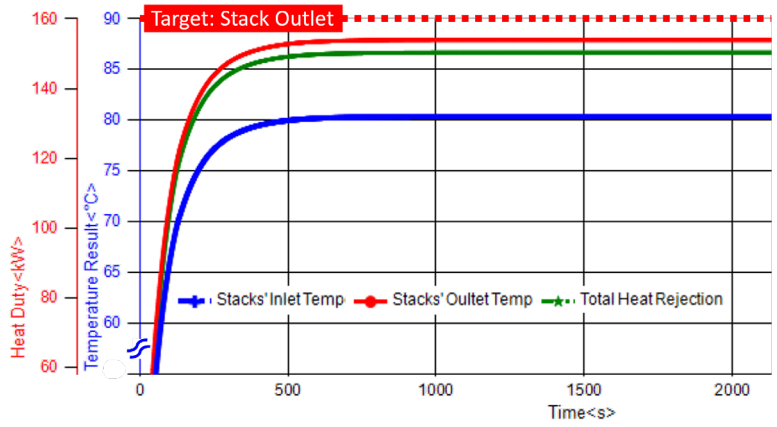
Accomplishments and Progress

Analytical Concept Evaluation – Fuel Cell Thermal Management System

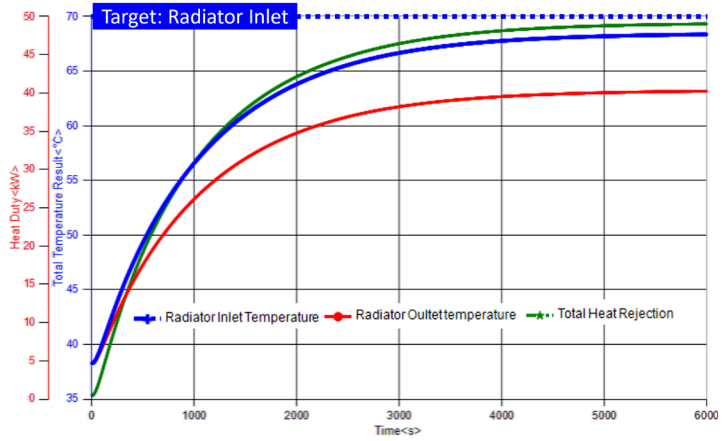


Cooling Circuit and Components	Total Heat Rejection		
	Max HR	Max Inlet Temperature (continuous)	Max Inlet Temperature (intermittent)
High Temp – fuel cell, intercooler, PTC heater	150 kW	80C	85C
Low Temp – compressor & inverter, inverters & motors (e-drive), DC-DC converters, PTU	55 kW	65C	70C
Battery and Cabin	9 kW	n/a	n/a

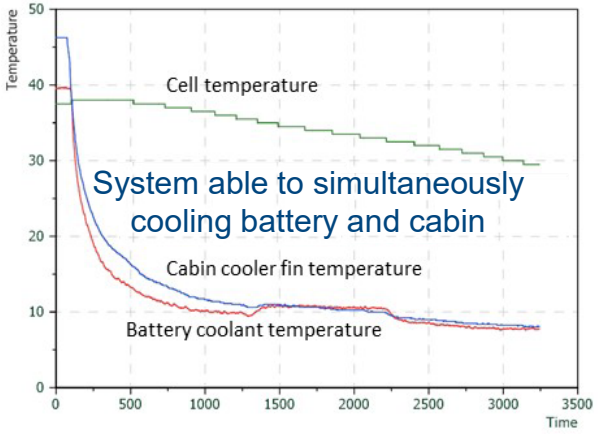
High Temperature Loop



Low Temperature Loop



Cabin & Battery Cooling Capability



Fuel cell cooling is challenging, requiring multiple loops, all targets are being met

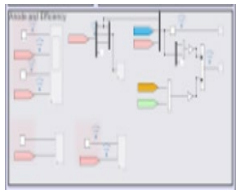
Any proposed future work is subject to change based on funding levels

Accomplishments and Progress: Fuel Cell System

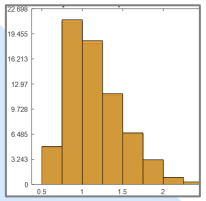
Systems Engineering Development Process

Vehicle Level:
Provided lifetime/durability/start-up criteria
- Used customer data logger or other sources

System Level:
Converted system data to stack attributes
- Used system modeling and test data



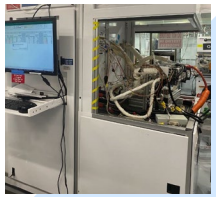
Stack Level:
Identified the most significant stressors
- Used transfer function guidance



Short Stack Level:
Developed short stack durability test protocols
- Used transfer function stressors

Coming in 2024…
Vehicle Testing:

System Testing:
Evaluate failures not covered by stack/BOP
- Testing to be determined



Stack Testing:
Evaluate failures not covered by short stack
- Testing to be determined

Short Stack Testing:
1) Membrane Degradation
2) Catalyst Degradation

Fuel Cell Development Effort Translated Customer Usage Data to Durability Stressors

Any proposed future work is subject to change based on funding levels

Accomplishments and Progress:

Analytical Concept Evaluation - Scalability, TCO and Environmental Impact

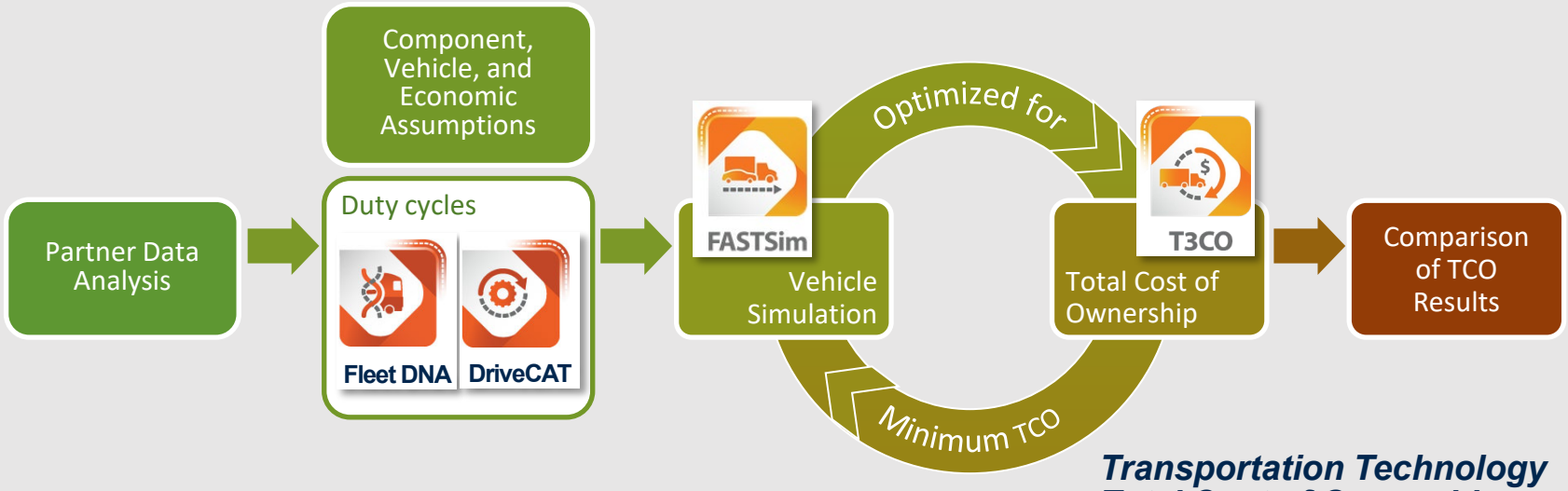
FY22-23 Data, Model Development and Initial TCO Results

Fleet Partners Data Analysis

- ☑ Fleet baseline data collection – 3 fleets
- ☑ Fleet operational characteristics
- ☑ Representative and edge-case drive cycles

T3CO Framework

- ☑ Vehicle data inputs
- ☑ Powertrain model development
- ☑ Baseline TCO model framework
- ☐ Initial TCO model results



Transportation Technology Total Cost of Ownership

FY23-24 Focus

TCO Model Refinement and Comparative Results

- ☐ Finalize BEV and FCEV powertrain model & TCO inputs
- ☐ H_2 Fueling and Infrastructure costs
- ☐ Full TCO comparative analysis – conventional, BEV, FCEV

Market Sector Analysis

- ☐ Identify key market sectors
- ☐ Fleet Chromosomes
- ☐ GHG & Environmental Impacts
- ☐ Assess scalability – beyond three fleet partner applications

Battery Life – FY24

- ☐ Battery duty cycles
- ☐ Battery chemistry
- ☐ Ambient conditions
- ☐ Assessment of battery life

BLAST

NREL is leveraging core modeling and analysis tools to evaluate fleet operations, develop drive cycles and model total cost of ownership.

Any proposed future work is subject to change based on funding levels

Collaboration and Coordination

Subcontractors

NREL (Transforming ENERGY)

- Assess Total Cost of Ownership
- Commercial Vehicle Partner Fleet Systems Analysis
- Freight and Vocational Fleet Systems Analysis
- Battery lifetime modeling
- Hydrogen fueling rate

FEV

- Fuel Cell System Development and Testing Services
- Vehicle Testing Facilities
- Netcom and LV architecture services
- Functional Safety engineering services

Customers

SoCalGas

- Crane Truck
- High Heat/Altitude/Grades
- On-Road/Off-Road/High GVW

- California - Gas Utility
- Servicing Southern California

Consumers Energy (Count on Us®)

- Boom Truck
- Cold Climate
- On-Road/Off-Road/High GVW

- Michigan - Gas and Electric Utility
- Servicing all lower Michigan counties

FERGUSON

- Box Truck
- Various Conditions
- On-Road/Construction Site

- North Carolina - Plumbing, HVAC, Industrial
- Servicing all 50 States

Two Subcontractor Awards / Three Fleet Customers

Ford

Any proposed future work is subject to change based on funding levels

Remaining Challenges and Barriers

- **Challenges**
  - Extreme cold weather operation
    - » Fuel cell, battery and propulsion system operating strategies are being developed to ensure robust operation in extreme cold climates.
  - Ford Super Duty Lifetime Durability
    - » Developing new accelerated durability tests that represent the appropriate use cases and stressors (different from ICE)
  - Local infrastructure deployment
  - ICE parity in MD CV applications (including TCO, uptime, payload)
- **Barriers**
  - H2 infrastructure
  - H2 cost (Green H2 scale)

H2 barriers must be resolved before industry-wide implementation and adoption

Proposed Future Work

2023

- **Propulsion System:** Complete design and vehicle packaging efforts that support concept attributes, targets and sizing
- **Scalability, TCO, Infrastructure:** Characterize fleet operations and develop representative and “edge case” duty cycles to feed the TCO analysis
- **Formal Phase 1 Go/No Go Analytical Confirmation and transition to Phase 2**

140kW FC net power w/ 20% parts reduction from dual 70 kW FC systems	**300+kW net vehicle power** w/ 75% tank-to-wheel efficiency improvement over gas ICE	**300+ mile range** w/ optimized 700 bar tank package, SAE J2601 fill time	**10k payload / 20k towing capability**

- **Fuel Cell:** Complete pilot vehicle fuel cell system builds and begin bench testing characterization prior to installation
- **Vehicles:** Initiate builds

2024

- Complete vehicle builds and commissioning (calibration development begins mid-2024)
- Continue fleet customer discussions to ensure pilot-specific vehicle builds meet vocation requirements

Accomplishments and Progress

Responses to Previous Year Reviewers' Comments

- **Project was not peer reviewed at the 2022 AMR**

Summary

- Concept selection and analysis of an F550 Chassis Cab Fuel Cell Propulsion system that meets the target attributes is nearing completion
- TCO, GHG and environmental impact studies are underway
- Ford is grateful for DOE recognition of the importance of this segment in SuperTruck 3 and our vocational customers are very excited to be participating in this collaboration.

THANK YOU!

Technical Backup
and Additional Information

Technology Transfer Activities

- **Ford plans to evaluate this technology and where it fits within Ford's ZEV Commercial Vehicle portfolio**
  - Best market segments/vocations
  - TCO
  - Current state of infrastructure and/or what is needed to be viable
  - When and how to scale

Acronyms

BEV	Battery Electric Vehicle
CO2	Carbon Dioxide
CV	Commercial Vehicle
DV	Design Verification
FC	Fuel Cell
FuSa	Functional Safety
GHG	Green House Gases
GCW	Gross Combined Weight
GVW	Gross Vehicle Weight
H2	Hydrogen
HD	Heavy Duty
HIL	Hardware-in-the-Loop
HMI	Human Machine Interface
HV EDS	High Voltage Electrical Distribution System
ICE	Internal Combustion Engine
LV	Low Voltage
MD	Medium Duty
MIL	Model-in-the-Loop
NVH	Noise Vehicle and Harshness
SIL	Software-in-the-Loop
SOC	State of Charge
TCO	Total Cost of Ownership
ZEV	Zero Emission Vehicle