Freight Emissions Reduction via Medium Duty Battery Electric and Hydrogen Fuel Cell Trucks with Green Hydrogen Production via New Electrolyzer Design and Electrical Utility Grid Coupling

Jacob Lozier (Principal Investigator)
General Motors LLC
DOE Project Award # DE-EE0009859
May 7, 2024

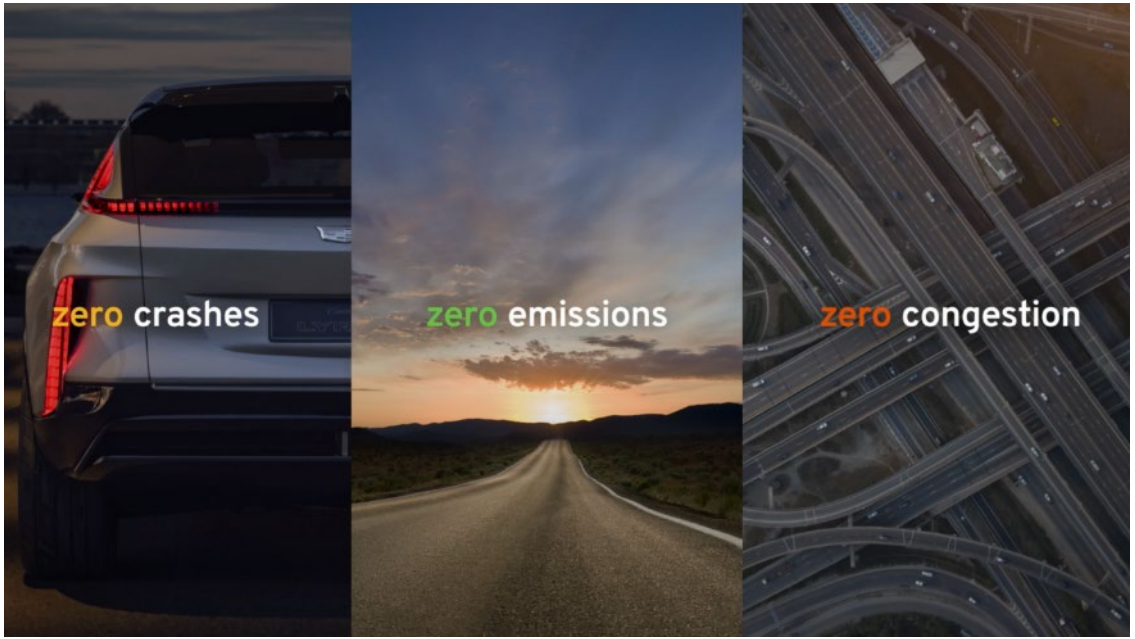
DOE Hydrogen Program
2024 Annual Merit Review &
Peer Evaluation Meeting
AMR Project ID # **TA058**



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Project Goal

GM Vision and Sustainability Goals



Sustainability Highlights

- Agreements in place to source 100% of our electricity for all U.S. sites from renewable energy by 2025, 25 years earlier than initial 2050 target.
- Announced plan to eliminate tailpipe emissions from all new, U.S. light-duty vehicles by 2035.
- Achieving carbon neutrality in our products and operations by 2040 and set Science Based Target initiative (SBTi) approved targets.
- Extending our technologies beyond our vehicles to meet the world's growing demand for more zero-emissions solutions.

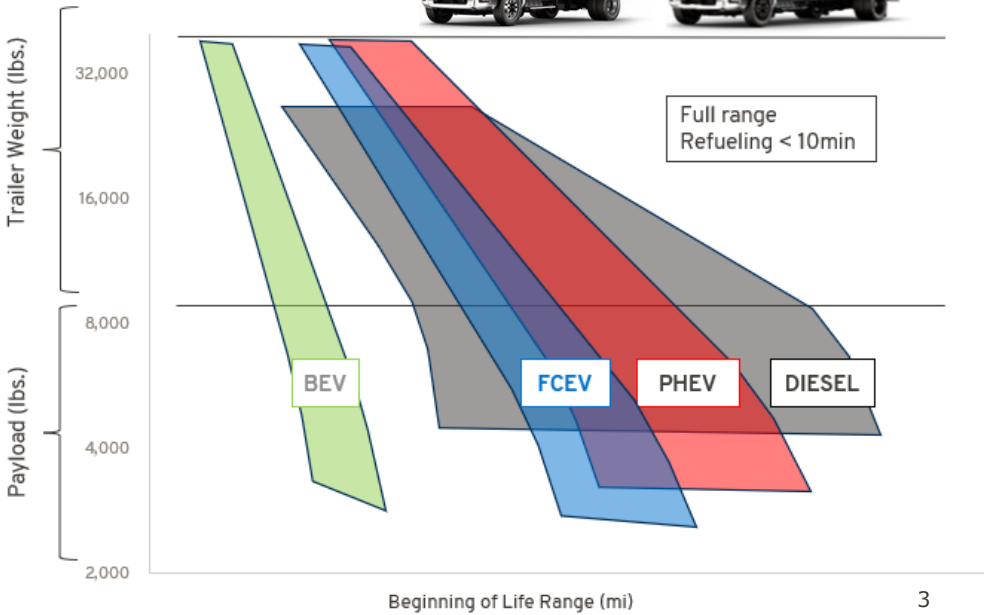
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Project Goal

Demonstrate a 75% reduction in Green House Gases (GHG) with Total Cost of Ownership (TCO) equal or better than the baseline Internal Combustion Engine (ICE) vehicles by:

- Modeling, data analysis, and simulation of medium duty trucks for improved propulsion system performance & durability
- Demonstration of medium duty trucks with advanced next gen fuel cell and battery electric propulsion systems
- Fleets fueled by low cost, onsite, clean hydrogen via a hydrogen-centric microgrid
- Equity analysis of zero emission medium duty truck impacts on underserved communities





Project Goal

Timeline & Budget

- Project Start Date: 07/01/2022
- Project End Date: 06/30/2027
- Total Project Budget: $65M
  - DOE Cost Share: $26M (40%)
  - GM Cost Share: $39M (60%)
- DOE Funds Spent: $2.5M*
- Cost Share Funds Spent: $3.8M*

*through February 2024
may not be fully billed yet

Partners

- Project Lead: General Motors, LLC
  - Jacob Lozier (PI)
  - Craig Gittleman (Technical)
- Partner Organizations (subrecipients)
  - Argonne National Lab (ANL)
  - Nel Hydrogen (Nel)
  - Southern Company (SoCo)

Barriers

- H2 Fueling / Cost
- Vehicle HD FCS Durability

Targets

- 75% Reduction in Greenhouse Gas
- Vehicle TCO ≤ ICE Variant
- Accelerated FCS Test Protocol equivalent to 20-30K Hours @ ~5X degradation
- Accelerated Electrolyzer Test Protocol equivalent to 10 years @ ~10X degradation

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

Relevance/Potential Impact

Project Activity	Potential Impact
Development of 99.8th percentile customer Medium Duty Truck (MDT) duty cycle - GM truck fleet data	Provide baseline for GM and shared DOE program accelerated stress test development
Development of accelerated durability testing protocols – fuel cell	Reduce time to market for novel, advanced FCS designs and FC vehicles
Development of accelerated durability testing protocols – electrolyzer	Reduce time to market for novel, low-cost electrolyzers
Electrolyzer field demonstrations	Hydrogen production cost reduction aligned with DOE's goal of $1 per 1 kilogram in 1 decade
Medium-duty FC & BEV truck integration for performance and durability demonstrations	Faster adoption of zero emission MD trucks for goods movement and vocational applications
Microgrid development and demonstration	Economically viable pathway to deploy charging and H2 filling infrastructure at scale
Data collection during fleet deployment will provide new insights regarding vehicle and component usage	Understand current technology capabilities Develop future R&D requirements for performance, cost, and durability

Approach

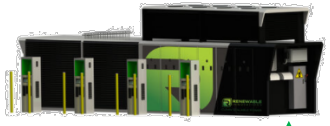
Argonne NATIONAL LABORATORY

Simulation and Modeling of Adoption & Impact

Southern Company

Scalable H2 Infrastructure via Electric Grid Coupling

Stationary Fuel Cell Power Generation



DCFC



Battery Electric MD Trucks

Southern Company

Utility Fleet Operator



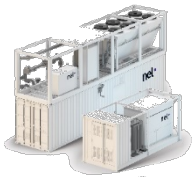
Electric Grid

Microgrid Controller



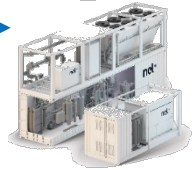
Photovoltaics

nel





H2 Storage

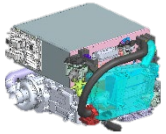


Prototype Electrolyzers



H2 Dispensing

Adv NG FCS





Fuel Cell MD Trucks

Pending

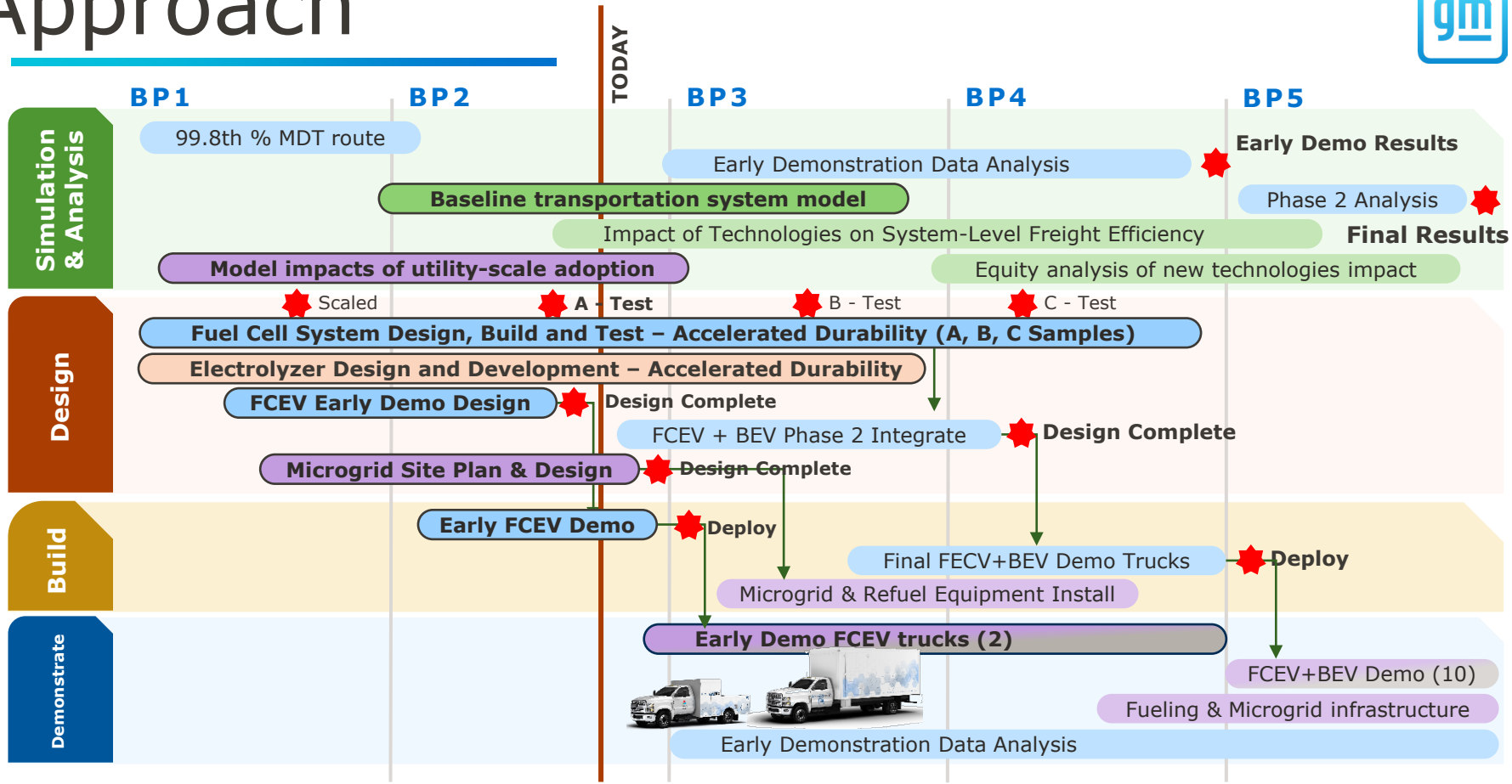
Freight Fleet Operator

Power

Hydrogen

*Images are intended to be a representation, not depict the final hardware design

Approach


TODAY
BP1
BP2
BP3
BP4
BP5
Simulation & Analysis
99.8th % MDT route
Early Demonstration Data Analysis
Early Demo Results
Baseline transportation system model
Phase 2 Analysis
Impact of Technologies on System-Level Freight Efficiency
Final Results
Model impacts of utility-scale adoption
Equity analysis of new technologies impact
Design
Scaled
A - Test
B - Test
C - Test
Fuel Cell System Design, Build and Test – Accelerated Durability (A, B, C Samples)
Electrolyzer Design and Development – Accelerated Durability
FCEV Early Demo Design
Design Complete
FCEV + BEV Phase 2 Integrate
Design Complete
Microgrid Site Plan & Design
Design Complete
Build
Early FCEV Demo
Deploy
Final FECV+BEV Demo Trucks
Deploy
Microgrid & Refuel Equipment Install
Demonstrate
Early Demo FCEV trucks (2)
FCEV+BEV Demo (10)
Fueling & Microgrid infrastructure
Early Demonstration Data Analysis
General Motors Prime
Southern Company
Nel
ANL
Freight (TBD)

Approach

Safety Planning and Culture

Hydrogen Safety Plan Submitted: January 2023

Feedback Received from Hydrogen Safety Panel (HSP): April 2023

Next Steps

Reviewing gaps in Safety Plan based on feedback, implementing updates

Working with sub-recipients to address plan shortfalls to drive safety measures

Safety Plan re-submission target Q2 2024

Examples

Early Demonstration truck development process includes safety experts – integrating best practices and defining requirement for new technology; Weekly safety calls for alignment

Development and validation test plans with pre task safety reviews. Example: initial pressurization of hydrogen storage – safety review, limit attendance, leak check joints, small steps, and post-task review

GM project participants are trained in high voltage and hydrogen safety

All Nel Electrolyzer systems go through a detailed HAZOP analysis: Systems certification

Current - ISO 22734:2008; Future - ISO 22734:2023

Accomplishments

Vehicle Simulation and Fleet Road Profiles

- ANL MD Truck Models Completed

MD Class 6	Diesel (baseline)	BEV	FCEV
Battery Size	-	200 kWh	90 kWh
Continuous Power	260 kW	260 kW	260 kW
Fuel Tank	40 gallons	-	25 kg
Refill / Charge Time	6 min	0.6-1.5 hrs	8 min
Range (miles)	400<	250<	500<
Fuel economy (MPGDE)	7.1	51	25.8
Efficiency	27.8	88.5	53.1
Green House Gas W/W (g/mil)	1754	330	489



Compared to Baseline

Improve

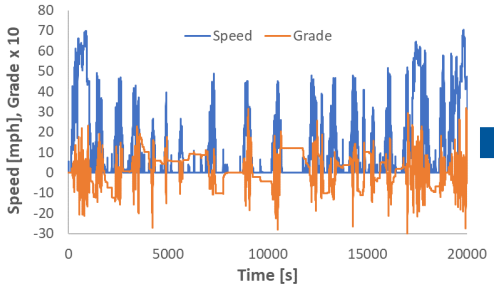
Reduce

Based on fleet DNA class 6 delivery cycle

- Full Payload -GVW 26,000 lbs
- 50.9 miles, Avg 17 mph
- 9.4 hrs op with on/off times
- 42.5 MJ/kg used for MPGDE

Fleet Cycle Development in Process

1. Record Drive Cycles
   - 1yr - 300 MD Chevy trucks
   - Southern Company utility trucks
2. Cycle Profiles – Velocity, Grade, Idle Time, ON/Off, Etc



3. Cycle statistics per drive cycle and vehicle

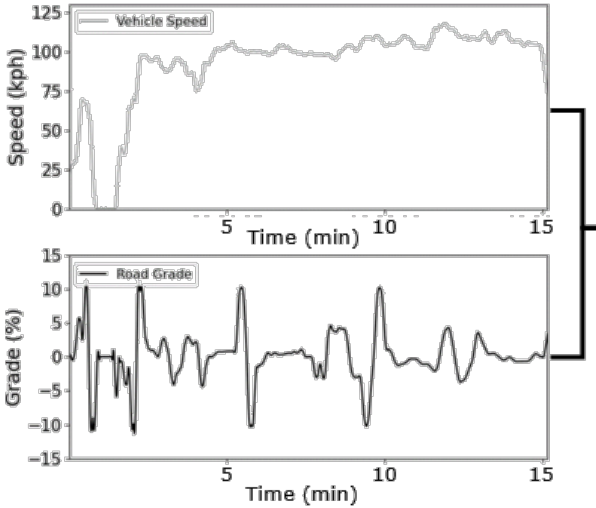
Analysis Parameters
Operating Time
Idle Time
Time Moving
Distance (mi)
Max Grade
Avg Grade
Elevation
Maximum Speed
Average Speed
# of Stops
Max Accel
Avg Accel
Max Deceleration
Avg Deceleration
Energy consumed
Kinetic Intensity
Max Wheel Power
Avg Wheel Power
Velocity Bins

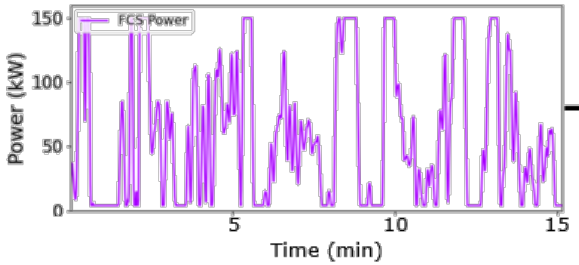
4. Select representative fleet cycles and group
   - Long haul
   - Utility
   - Delivery

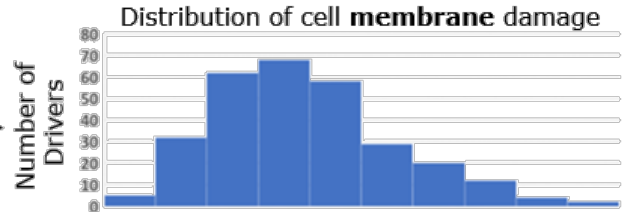
Accomplishments

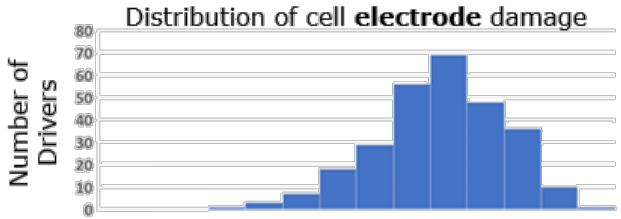
Defining the baseline customer stress

Extract customer behavior (second-by-second) → **Simulate FCS behavior (second-by-second)** → **Apply damage models (vehicle-aggregate level)**





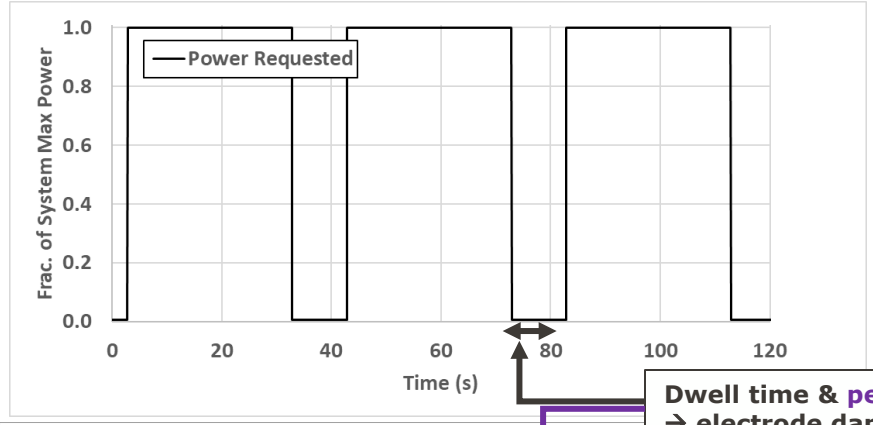


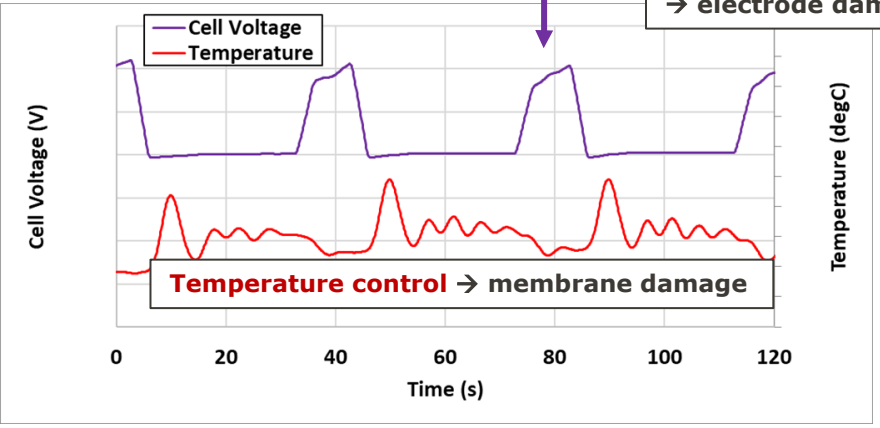


- Use field data we simulate FCS behavior then extract the stress of the 99%-ile customer.
- This becomes the comparison point for the accelerated cycle(s)

Accomplishments

Defining the Accelerated Test Cycle





- The stress of the 99%-ile customer has been identified from the data (prev slide).
- The accelerated test cycle dwell, peak voltage and temperature is calibrated on the test stand, so the FCS reaches the desired stress level.
- The test stand system creates the interface requests and conditions so the FCS production software control system responds as it would in vehicle.

Cycle Name	Mem. Factor	Ele. Factor
99 %-ile MD Cust.	1.0	1.0
US06 Simulation	1.0	1.2
Tuned A.S.T.	6.4	5.9

Tuning Parameters	
Control Temp, degC	80
Dwell Time, s	10
Power time, s	30

Accomplishments

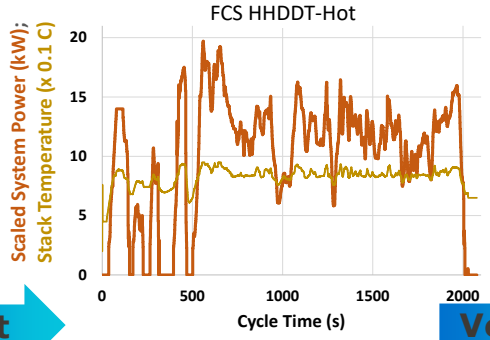
Scaled Prototype FCS Testing

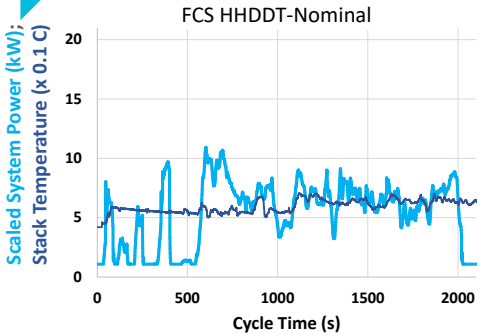
- The scaled fuel cell system is a flexible testing platform used to evaluate candidate components, materials and controls.
- Systems with production candidate materials run proprietary (Neo 9X) and public (HHDDT) cycles to verify the degradation model.
- **Durability tests show the model agreeing well at low power for this wide range of acceleration!**
- High power (100% rated level) data does not agree as well and showing more error when reaching higher levels of performance loss.



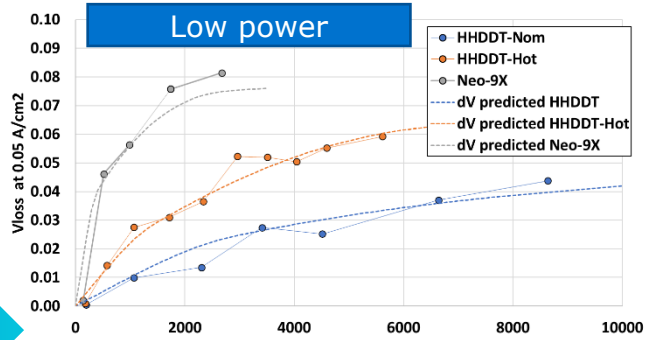
general motors

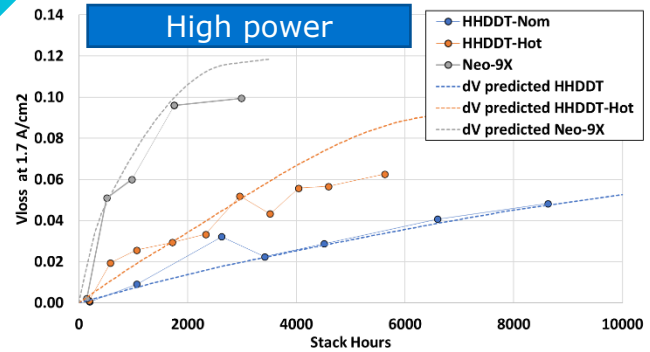
Test





Verify



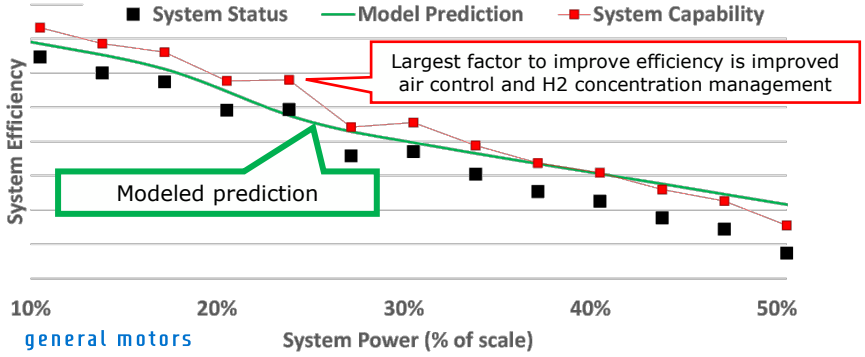


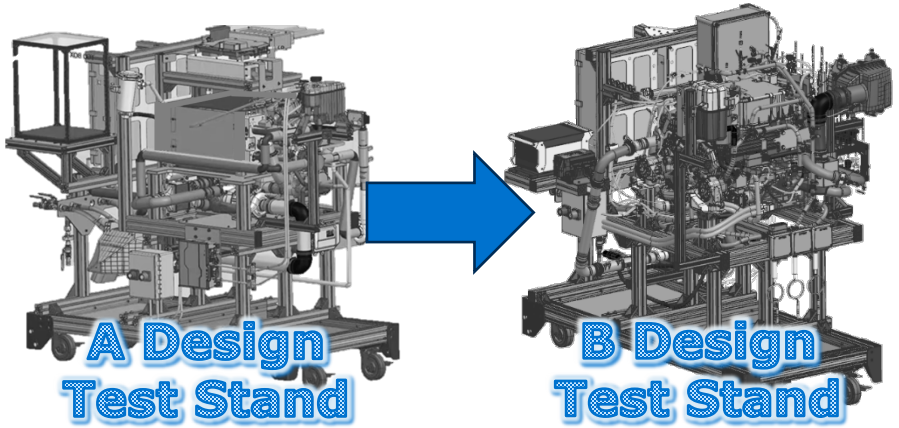
Accomplishments

Advanced A Sample Prototype First Power and B Sample Design Freeze

- The A sample prototype system made first power in July and Max power in August, and we currently have two systems running.
- Testing shows a path to >62% peak efficiency and >50% efficiency at full power with ongoing development focus.
- FCS Design Frozen for B Sample module. Test stand cart design completed shortly after.
- BETA builds with production-intent components and layout to validate targets
- Build of first module is currently underway → ~30% complete
  - Target Completion by end of Q2 2024



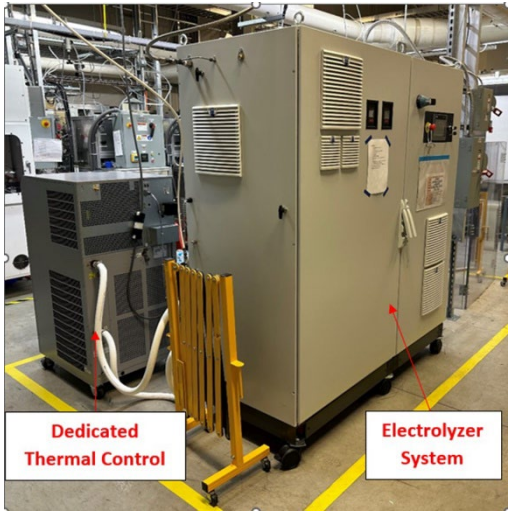




Accomplishments

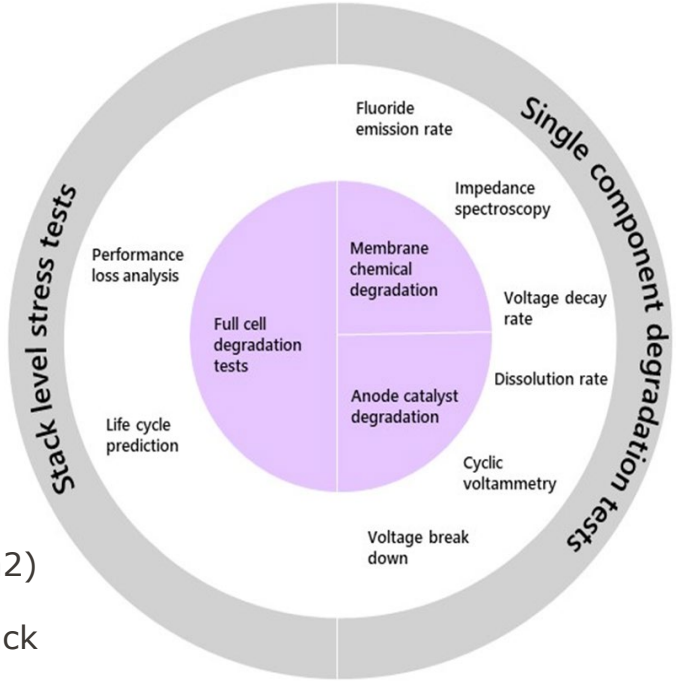
Electrolyzer Design & Development – AST

- Develop Accelerated Stress Tests (AST) to predict electrolyzer life-cycle hours
- Combine GM & Nel know-how



Test Station Details

- Commissioned Q3/Q4, 2023
- Multicell test capability (>650 cm2)
- Translate component AST's to stack
- Validate AST's



Accomplishments

Early Demonstration Trucks

- Integration designs complete
  - Vocational Service Support Demonstrator
  - Freight Body Demonstrator

- Performance Expectations
  - Silverado 5500 GVWR 19,500lb
    - Powered by HYDROTEC Fuel Cells
  - Greater than 300 kW total power generation
  - 800V native electrical architecture / components – fuel cell, RESS, propulsion, pump, fan
  - Offboard Power (110V, 220V, potential 800V)
  - More than 300 Miles Range ALVW
  - 12.3kNm RWD eBeam axle



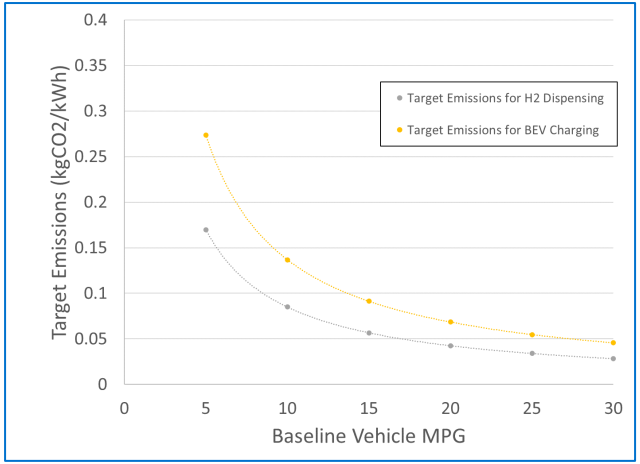


Accomplishments

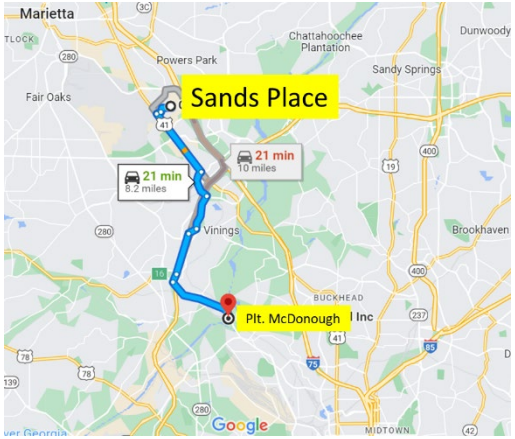
Southern Company Scope of Work



- Collection of baseline fueling and performance data
  - MPG ranges from 5.5 to 9.4 and average of ~8,000 miles per year
  - Additional telematics provided to GM for drive train optimization
  - Trucks from Sands Place facility



- Simulation and analysis for charging and electrolysis scenarios for GHG and price optimization
  - Operational model completed to calculate maximum price and GHG from primary power (typical grid ~0.4 kgCO2/kWh)
  - Most of the stored hydrogen needed to support resilient power
- Model impacts of utility-scale adoption
  - Finalizing contract with Electric Power Research Institute (EPRI) to provide assessment of vehicle demands and potential impacts to energy system with significant adoption of FCEV and/or BEV utility vehicles
- Site planning and design for SoCo Fleet Site
  - Site selected at Plant McDonough (metro Atlanta)
  - Layout completed and engineering in progress
  - Stationary fuel cell system under development



Accomplishments and Progress

Responses to Previous Year Reviewers' Comments

"The mechanism preventing membrane and electrode damage factor is not evident."	The primary mechanisms for damage are temperature and voltage, as reported. Prevention requires management of these mechanisms. Damage models are developed based on 99.8 %-ile drive cycle and applied for total system analysis
"The project needs to capture key performance indicators on the target or end goal for future work."	Key Performance Indicators are defined as % reduction in GHG and TCO ≤ conventional? This includes sub-targets which are optimized to get optimal TCO.
"The project has a lack of scale…Building a larger number of trucks that more closely represent the way [companies] would use a fleet of entirely hydrogen fuel cell vehicles and BEVs would reveal such infrastructure constraints, if they existed.	The Purpose of this ST3 project is demonstration of GHG reduction and TCO opportunity at scale. Fleet learnings are expected in BP5 with Southern Company running 6 trucks (plus any other applicable EV fleet vehicles) on the Microgrid – this will begin to reveal the concerns mentioned.
Prototype fuel cells are being used in commercial fleet assets, which increases risk, both in performance and maintenance.	There is increased risk in prototype applications. However, early demonstration trucks use early production FCSs built at our partnership Brownstown, MI plant.
The project's novel approach in durability tests needs better review for covering edge cases.	The baseline truck drive cycle (US06) used to define the accelerated durability cycle represents edge case 99.8th %-tile fleet application. Electrolyzer durability (AST) protocol is being similarly defined.

Collaboration / Coordination

Southern Company

Sub, Industry
Noah Meeks

- Demonstrating the medium duty trucks in vocational (electric utility) applications including baseline vehicle identification and data collection
- Design, installation, operation, and modeling of hydrogen-centered microgrid

nel

Sub, Industry
Marcelo Carmo

- High efficiency low cost electrolyzer system development
- Electrolyzer accelerated durability test development and testing

Freight

Industry
TBD

- Demonstrating the medium duty trucks in freight applications including baseline vehicle identification and data collection
- Change in partner in process

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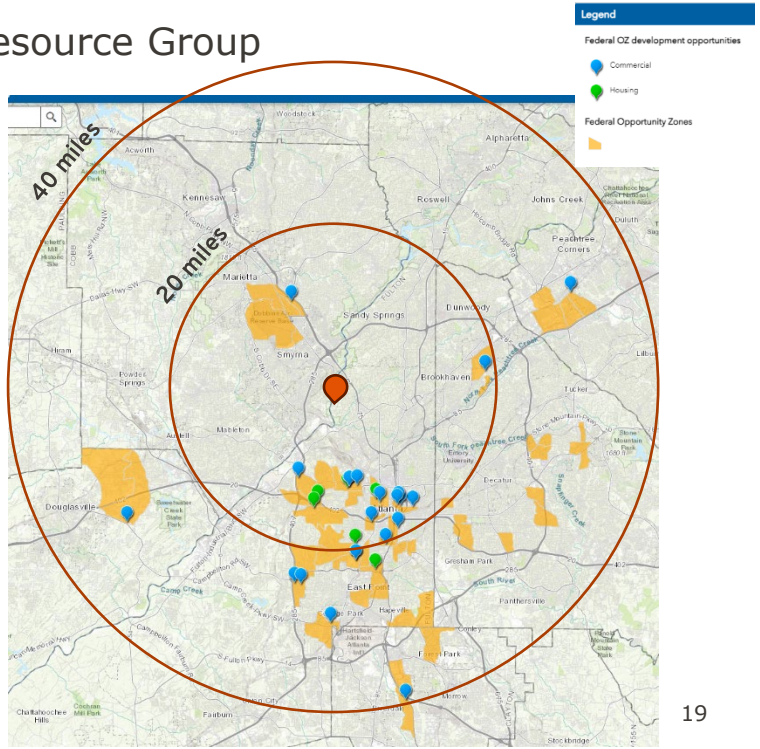
Sub, National Lab
Natalia Zuniga

- 99.8%-tile durability cycle development (with GM)
- Quantification/assessment of project potential impacts on program metrics (GHG, system/freight efficiency, TCO)

DEIA Plan

Community Benefits and Activities

- Diverse Project Team
  - 1 in 3 GM employees participates in an Employee Resource Group
  - Key Female Personnel
    - Nel Board of Directors 50% female
- Benefit to Underserved Communities
  - Communities where demonstrations operate will benefit via a reduction in GHG Emissions
  - Equity Analysis of project outputs (ANL) in BP4/5
    - Focus on congestion, emissions, accessibility to charging/refueling stations & economic benefits
    - ANL POLARIS tool – determine impact to neighborhoods



Federal Opportunity Zone, Southern Company site, GA

Remaining Challenges & Barriers

- Fuel cell system durability and efficiency targets for heavy duty vs light duty applications
  - Working collaboratively in industry to define drive cycles
- Validation of achievement of durability requirements for fuel cell and electrolyzer system
  - Development and validation of novel accelerated durability tests
  - Identification of real-world degradation rates and failure modes
- Short/medium term hydrogen fueling hurdles
  - Temporary “mobile” 700bar fueling options are limited, expensive, with long lead times
  - Mid-term plan defined – contract in place; Short term plan working
- New Freight demonstration partner update in process, pending contract agreements and DOE approval
  - On target for Early Demonstration deployment

Proposed Future Work

2024

- Build complete of Early Demonstration trucks and delivery to fleet locations in Q3 2024
- Complete FCS A sample testing for durability and performance over a range of operating conditions
  - Testing includes freeze start capabilities and confirming beginning of life power and efficiency
- Complete FCS B sample prototype builds and initial testing
- Complete development of accelerated electrolyzer durability test protocol
- Finalize microgrid design and begin site prep for Phase 2 vocational fleet

2025

- Test B sample FCS for durability using accelerated drive cycle
- Freeze FCS C Sample Design – mechanization complete, all components selected
- Build C sample prototype FCS
- Begin Installation of Microgrid equipment at Southern Company site
- Release designs for Phase 2 demonstration truck integration

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

Summary

General Motors LLC and the Fuel Cell Development Team will partner with Argonne National Lab, Nel Hydrogen, Southern Company and Metro Delivery to collaboratively demonstrate 75% reduction in Green House Gases (GHG)

- Continued analysis of baseline fleet data; developing simulations and fuel cell damage models
- Prototype A sample FCS on test, entering testing with accelerated durability protocol
- FCS B sample design released, and build started
- GM/Nel Collaboration in stack AST validation on commissioned Electrolyzer test stand hardware
- Early demonstration fleet build in progress, on track for Q3 2024 delivery
- Southern Company baseline fleet identified for data collection and analysis
- Finalizing microgrid engineering and designs
- On track to achieve project tasks and goals