DAIMLER TRUCK

Ultra-Efficient Long-Haul Hydrogen Fuel Cell Tractor

Darek Villeneuve, Principal Investigator, Vehicle
Jeff Murawa, Powertrain

May 7, 2024

Project ID: TA056
DOE project award #: DE-EE0009860

DOE Hydrogen Program
2024 Annual Merit Review and Peer Evaluation Meeting

FREIGHTLINER FUSO WESTERN STAR Thomas BUILT BUSES BHARATBENZ SETRA

Project Goal

"To demonstrate how a substantial (75% or greater) reduction in the GHGs and local pollutants from the movement of goods in trucks can be achieved in a way that is economical and scalable"

Relevance: Develop, build and test a Class 8 hydrogen fuel cell truck that achieves the following targets:

Vehicle Performance

- 6.0 miles per kg H_2 over prescribed regional and long-haul drive cycles
- 600 miles range per tankful
- Equivalent payload to baseline diesel tractor trailer
- Show analytical pathways to 25,000-hour lifetime

Reduce Carbon Intensity of Fuels *(in partnership with Linde)*

- Investigate pathways to produce hydrogen with lower carbon intensity than the diesel fuel baseline

Maximize Freight System Performance *(in partnership with Fleets)*

- Investigate the optimal fleet mix of zero emission vehicles (BEV, FCEV) and infrastructure which maximizes freight system efficiency

Two long-haul sleeper fuel cell vehicles will be tested

Overview

Timeline

- Project start date: May 1, 2022
- Project end date: April 30, 2027
- Percent complete: 35%*

Budget

Total Project Budget: $54,005,955

- Total DOE Share: $25,791,669
- Total Cost Share: $28,214,286
- Total Funds Spent*: $10,329,768
- Total Federal Share*: $4,918,262
- Total Cost Share Funds Spent*: $5,411,506

(* as of February 28, 2024)

Partners

Sub-Recipients

- Linde
- Michelin
- Mahle Behr
- Mahle Filter Systems
- Auburn University
- Oregon State University

National Labs

- Oak Ridge National Laboratory
- National Renewable Energy Laboratory
- Argonne National Laboratory

Fleet Partners

- Schneider National
- Walmart

Relevance and Potential Impact

DOE Goals

- Lower greenhouse gas emissions
- Difficult to decarbonize heavy duty transport
- Enable hydrogen end use applications at scale

Project Goals

- DTNA leader in long-haul segment
- Similar payload to diesel truck
- Investigate liquid hydrogen fueling of 10 kg/min
- Single fill up has >600-mile range

HD long haul difficult segment to decarbonize

Approach

Budget Period 1
- Simulation
- Analysis
- Main Path Defined for B-sample concept vehicle

Budget Period 2
- Main Path Design
- B-Sample build
- System Commissioning

Budget Period 3
- Vehicle commissioning
- B-Sample Testing
- Final Demo Concept
- Simulation

Budget Period 4
- Final Demo Design
- Final Demo Build
- Vehicle Commissioning

Budget Period 5
- Final Demo Optimization
- FE Validation Test
- Final Report

Program status

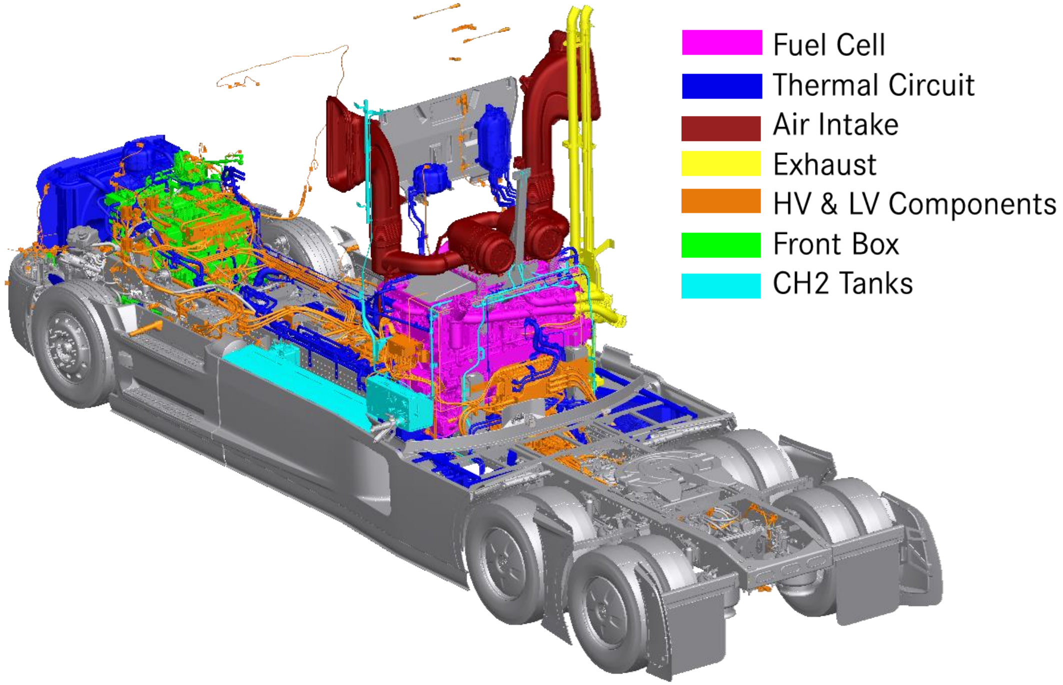
2022/2023 | 2023/2024 | 2024/2025 | 2025/2026 | 2026/2027

Phase	Milestone	Status	Completion Date
Budget Period 2	All designs for B-Sample vehicle are released. All initial parts design and Bills of Material are complete.	100%	Q1 2024
	All vehicle parts are ordered and received in-house	70%	Q2 2024
	B-Sample vehicle assembly complete	20%	Q3 2024
	Go / No Go: Verification tests, low & high voltage commissioning successfully completed on B-Sample per ECE-R100. Vehicle power on.	0%	Q3 2024

5 budget periods, 2 vehicles

Accomplishments - B-sample design and build

Vehicle Design

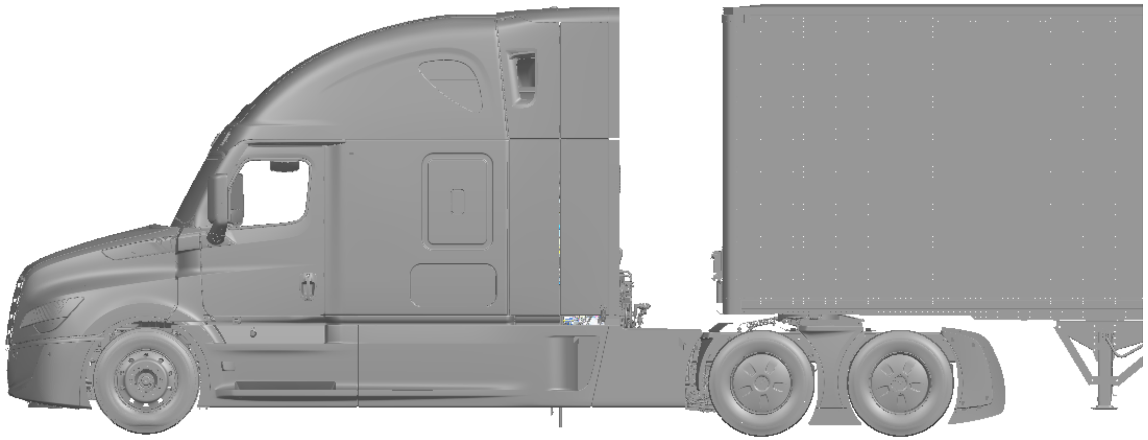


Vehicle build

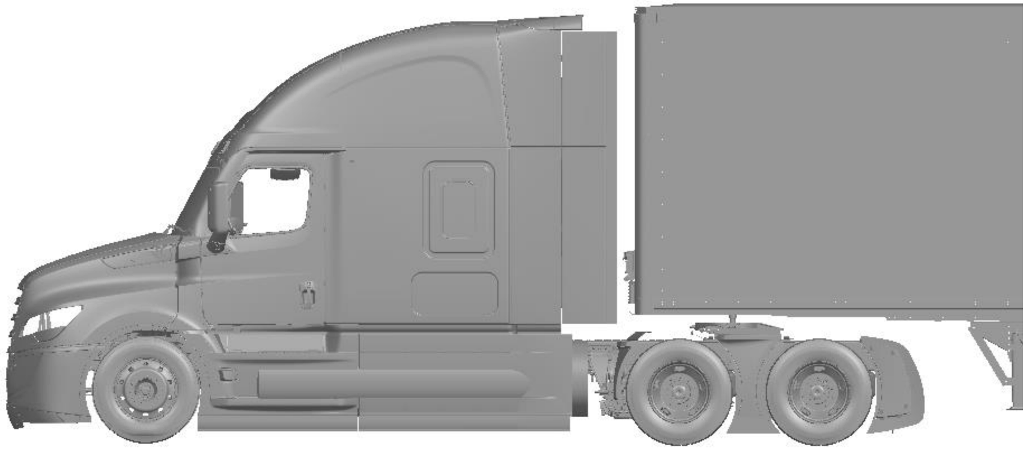
Design completed; build started

Accomplishments – Vehicle Strategy

B-Sample	
• Chassis/Cab	= Tractor 315 Tires / 126” BBC, 72” Slpr
• eAxle	= 6x2
• Fuel Cell System	= B Sample Fuel Cell System behind cab
• H_2 Tank Capacity	= 700 Bar CHG saddle tanks – 30 kg
• HV Battery Capacity	= 200 kWhr Battery
• Cooling System	= >200 kW heat rejection



Final Demonstrator	
• Chassis/Cab	= Tractor 315 Tires / 126” BBC, 72” Slpr
• eAxle	= 6x4
• Fuel Cell System	= C sample fuel cell underhood
• H_2 Tank Capacity	= 100 kg using sLH2
• HV Battery Capacity	< 100 kWhr Power battery
• Cooling System	= >200 kW heat rejection



B-sample learnings drives final demonstrator design

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

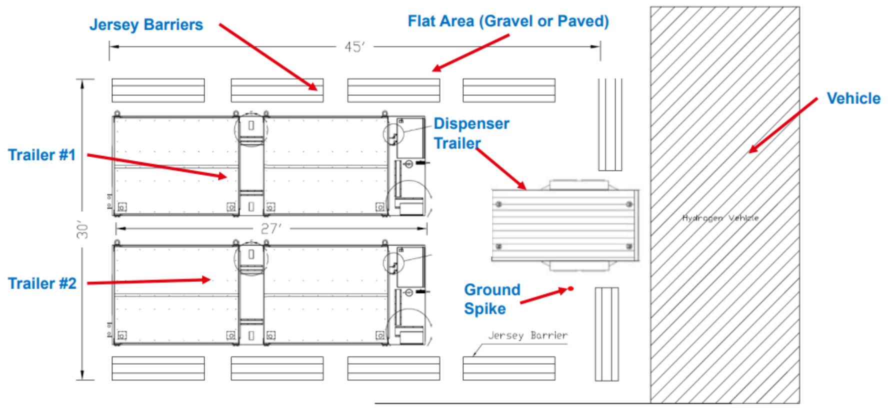
Accomplishments – Hydrogen Safety & Compressed status

- Hydrogen safety plan evolution
  - Integrating feedback from HSP review
  - B-sample design review completed
  - Hydrogen safety training by 3rd party expert
  - Developing H2 safety strategy roles similar to HV

- Facility updates
  - Submitted permit applications for CHG fuel dispenser and repair garage with AHJ
  - Requested updates to NFPA 2 for LH2 repair garage
  - Beginning site prep planning for sLH2 dispenser

• Compressed hydrogen gas dispenser site design completed, deploying Q3 2024

H2 Safety training/roles



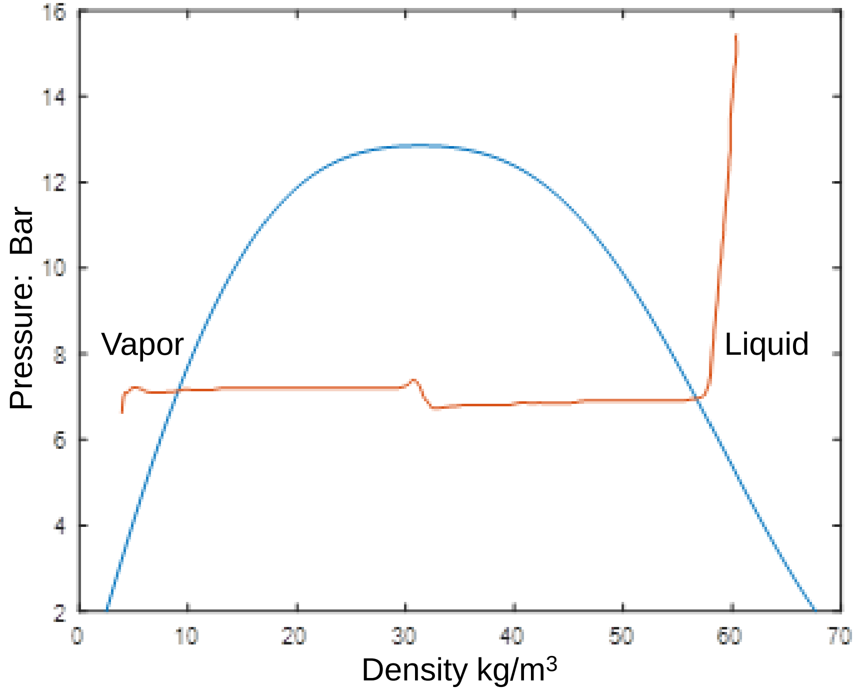
Linde CHG Dispenser Layout

Accomplishments – Liquid Hydrogen status

- Liquid hydrogen system design
  - Vehicle integration studies started
  - Supplier selection process launched

- Subcooled Liquid Hydrogen (sLH2) prime path for final demonstrator (2026/27)
  - Site planning started
  - Incorporating lessons learned during CHG activity
  - Linde conducting analysis for green hydrogen supply

- Reviewing hydrogen planning with local municipalities and global team
  - Sharing lessons learned on building updates
  - Leveraging future project overlap potential for hydrogen supply and dispensing



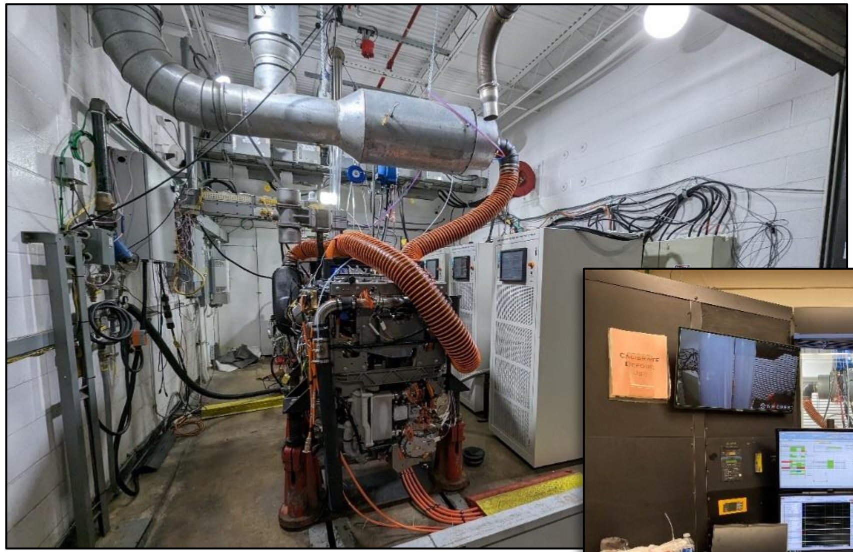
sLH2 fill event data from Feb 7, 2024, in Germany

Accomplishments – B-Sample Powertrain Development

- Fuel Cell System (FCS) for B-sample truck is performing well
- Development and validation of system ensuring confidence in B-sample truck integration

FCS for B-Sample Successfully Built

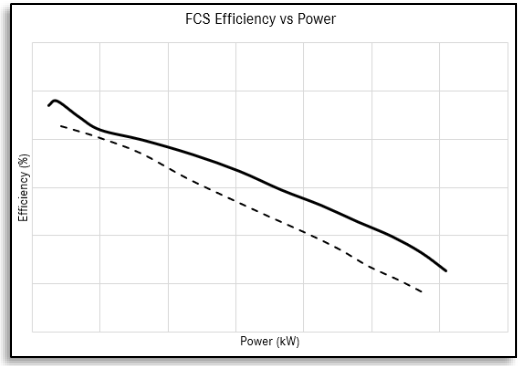
Prototype FCS assembled in Detroit Powertrain facility.
Instrumented, leak tested & low voltage commissioned.

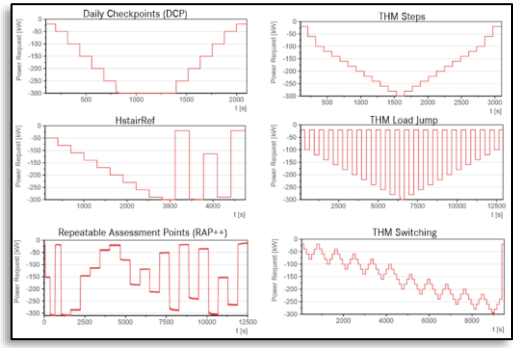


FCS for B-sample Successfully Validated

Test cell integration completed and fully commissioned
Fuel Cell System initial testing successfully started Nov. ’23

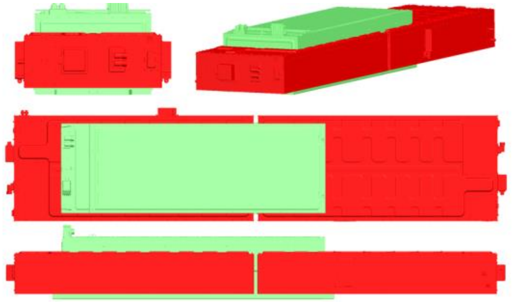
- ✓ FCS coolant circuit calibration
- ✓ Operating Conditions & Limits Verification
- ✓ Polarization Curves & Power Curves
- ✓ Exhaust system Validation
- ✓ Vehicle Drive Cycles
- ✓ eDrive coolant circuit flow characterization
- ✓ FCS Software Update & Commissioning
- ✓ HPR Testing (hydraulic/thermal)
- ✓ Vehicle ECU testing, System software validation





Status Overview - Powertrain Battery & Hybridization Concept

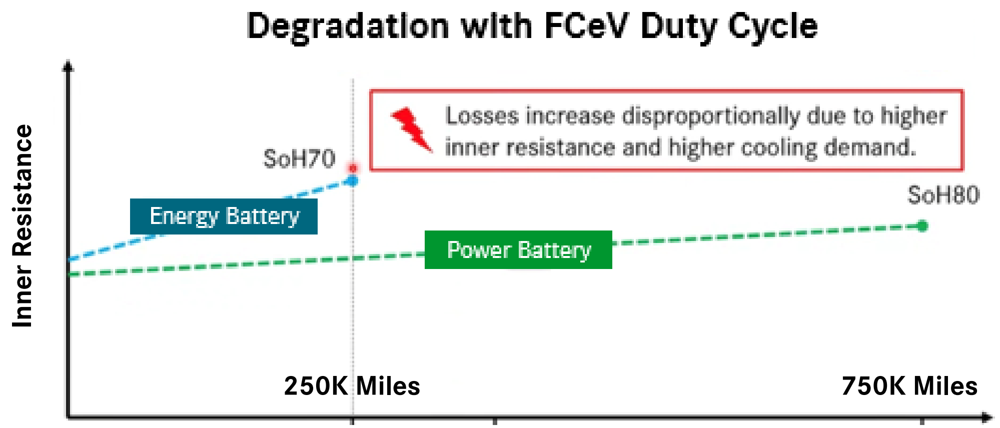
B-Sample Vehicle Status



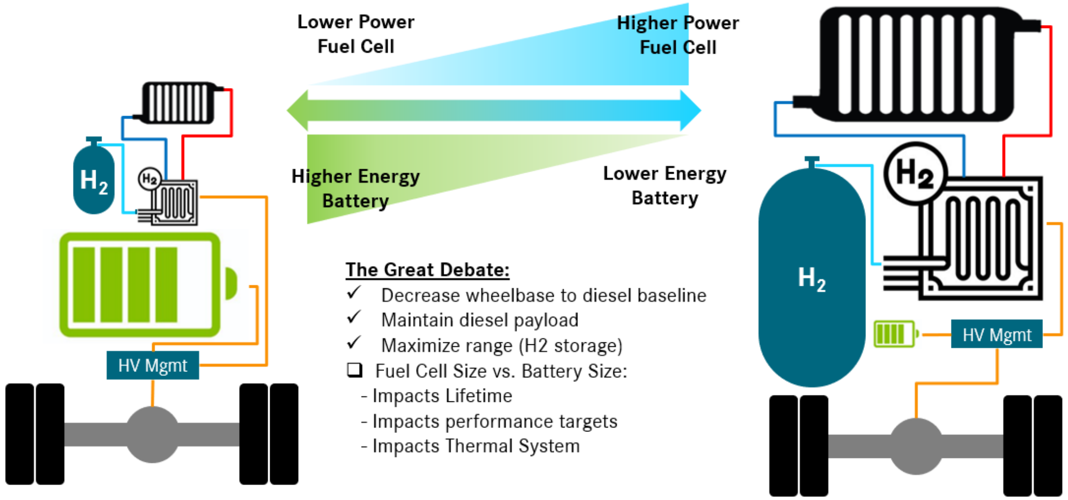
<u>Original Battery not available (red):</u>
100kWh Usable Energy (2x50)
"Power" Battery

<u>Fall-Back / Current Battery (green):</u>
200kWh Usable Energy
"Energy" Battery

No vehicle performance limitations expected for concept truck.
Not optimal concept + lifetime durability concerns (no risk to ST3).
Battery change driving 6-month B-sample truck delay



Path Forward

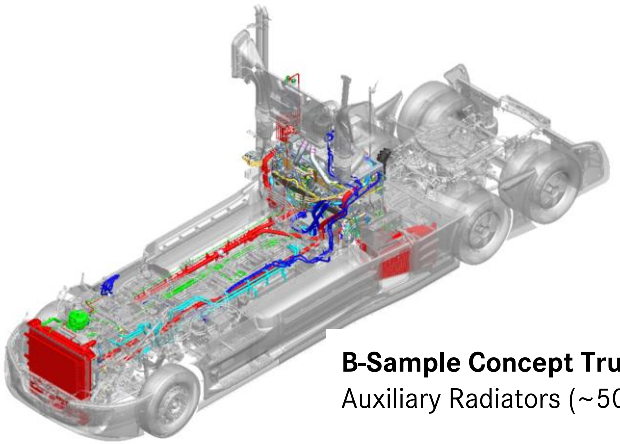


- **Power cells are desirable for the stability and increased life in highly transient operation**
- Sourcing power cells for a HD fuel cell battery system is challenging due to the very limited market
- While FCeV battery requirements may suit an energy cell, the longevity demands and expected battery down-sizing trend further give advantage to a power cell

Status Overview – Thermal System Challenges

Thermal System Performance vs FC vs. Battery Sizing Are All Related:

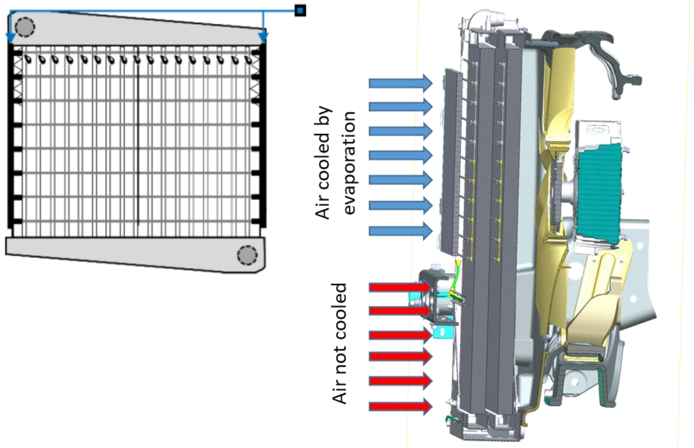
- Downsizing the HV battery requires greater sustained fuel cell power
- Increasing thermal system heat rejection allows for increased sustained fuel cell output power, in turn reducing battery capacity requirement
- Fuel cell exhaust water could be used for **evaporative cooling** if the thermal system can handle the water pH levels, environmental dust, cold ambient conditions, and protection of components that can corrode downstream of an evaporative cooler outlet

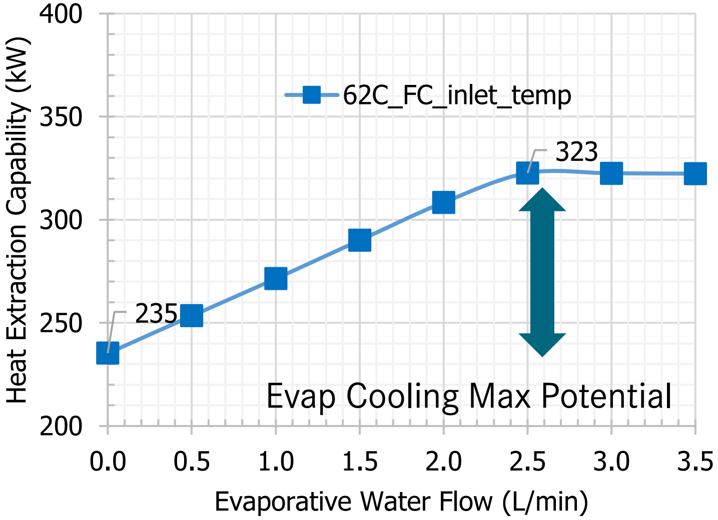


B-Sample Concept Truck:
Auxiliary Radiators (~50% of cooling)

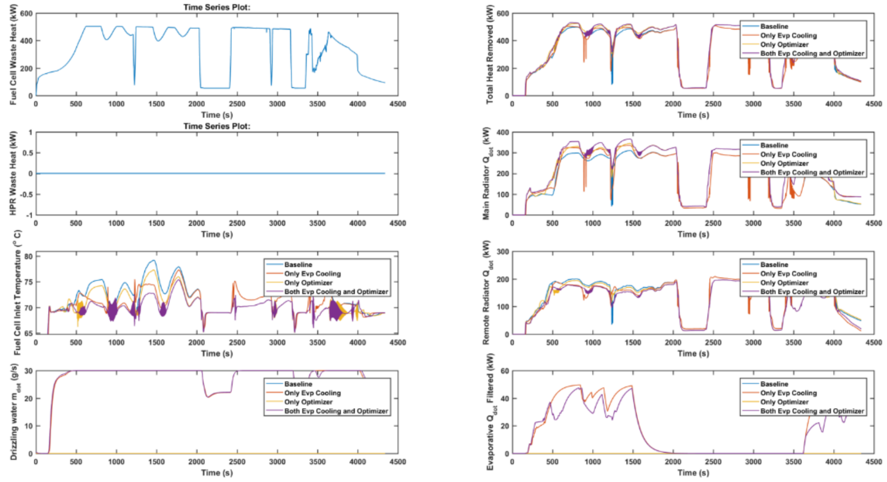
Final Demo Desired State:
Shorter wheelbase, Increased H2 storage

Evaporative Cooling Concept Study in B-Sample Vehicle:





Embedded SW Implementation Developed in MATLAB/Simulink for Proto Controller:



Accomplishments – Response to Previous Year Reviews' Comments

- The technical practicality of vehicle fueling with sLH2 is not a sure thing, so the reviewer will watch to see if it can be achieved.
  - ✓ *We have addressed this issue sharing global lessons learned with a recent public fueling station developed by Daimler Truck and Linde in Germany in our Technology Transfer slide.*
- Cooling and durability barriers are identified but not completely addressed. Project should provide more details on cooling optimization.
  - ✓ *Cooling development is not completed. However, based on simulations shared here with future work planned, more details can be forthcoming.*
- Discussion around the need for tire development
  - ✓ *The total cost of ownership on Zero Emission Vehicles is critical for vehicle acceptance. Initial testing has shown significant TCO is driven by increased tire wear for e-vehicles. Balancing performance and tire design should greatly reduce tire based TCO on e-vehicles. Diesel tires are not a direct replacement for e-vehicles because of wear characteristics and ability to handle higher axle loads.*

Collaboration: Sub-Recipients and National Lab Partners

Well-to-Tank Lifecycle Analysis
Fueling solutions and standards (liquid & gaseous)

Low Rolling Resistance and High Longevity Drive Tires
Low Rolling Resistance and High Load Carrying Capacity Steer Tires

Thermal and Air Filtration Systems for Future Mobility

Connected and Automated Vehicles
V2X technologies, traffic impact evaluation

Power Electronics
Thermal & Energy Management Controls

Thermal/Mechanical Analysis of Power Electronics and Electric Machines

HV Vehicle Architecture, eDrive Benchmarking
Power Electronics and Electric Machines

Li-Ion Cell modeling and testing
Freight Systems Analysis

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

DEI Community Benefits Plans and Activities

- Educational Opportunities
  - Recruited and hired underrepresented employees

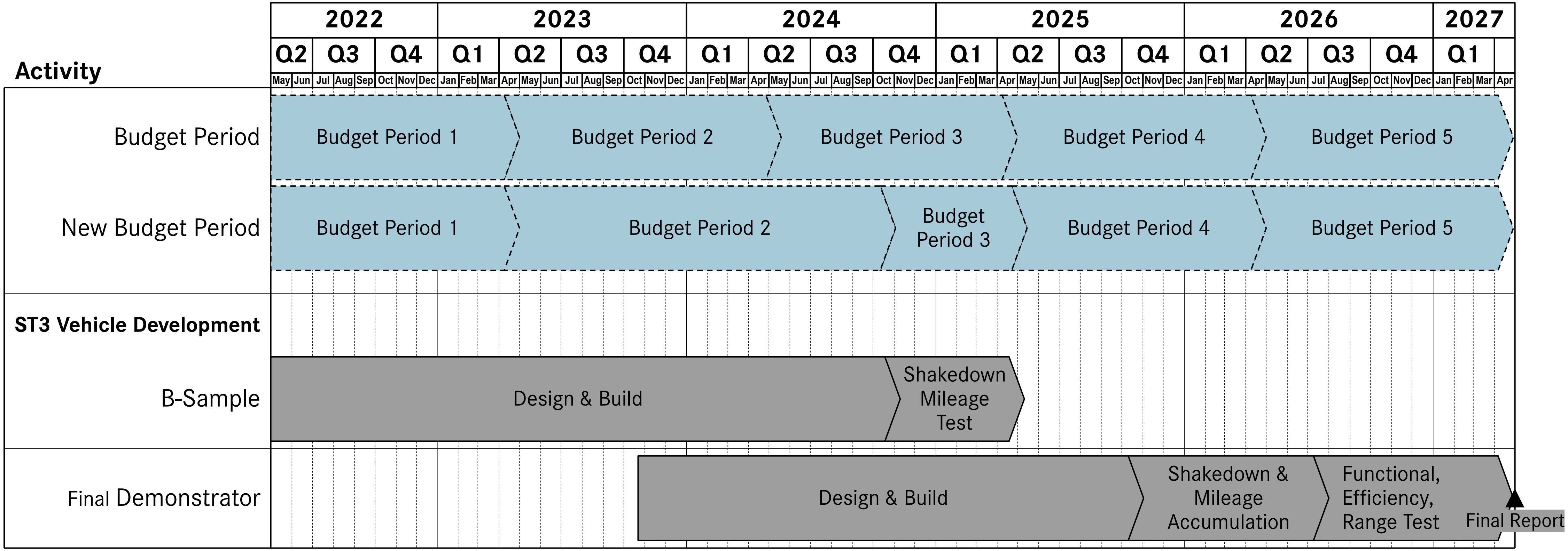
- Program staff
  - 2nd year partnering with In4All
    - STEM activities in local underserved elementary schools
  - Supporting internal DEI building champions program
  - On-going DEI training for all

- Testing planned in Madras, Oregon in Budget Period #3, in an underserved community

Remaining Challenges and Barriers

- Cooling
  - Fuel cell needs higher operating temperatures to enable smaller cooling systems
- Durability in HD environment
  - Fuel cell and battery lifetime from drive cycle strategy
- Powertrain configuration
  - Balance of fuel cell power, efficiency and battery size
- Market acceptance
  - Infrastructure availability for hydrogen
  - Vehicle TCO

Proposed Future Work: Timeline and Next Steps



Phase	Milestone
Budget Period 3	Sizing and spec of final demonstrator vehicle fuel cell
	B-sample vehicle functional test completed with report available
	Packaging concept of the final demonstrator vehicle completed
	Go / No Go: Successful testing on the B-sample towards project objectives. Final demonstrator vehicle architecture defined.

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

Summary

Accomplishments

B-sample Concept Vehicle
- Vehicle packaging and designs finished
- Fuel cell built and test cell evaluation completed
- Hydrogen safety and vehicle plans defined
- Fuel cell efficiency and battery sizing for final demonstrator being worked through simulation

Subrecipients
- Universities and National labs began work on benchmarking.
- Michelin, Mahle initial parts under development with delivery scheduled in 2024.
- Linde mobile refueler on schedule to support first vehicle build