HIGH PRESSURE FAST RESPONSE DIRECT IINJECTION SYSTEM FOR LIQUIFIED GAS FUELS USE IN LIGHT-DUTY ENGINES

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OVERVIEW

WM INTERNATIONAL ENGINEERING
DARIEN, IL - USA

TIMELINE

- PROJECT START: April 2022
- PROJECT END: April 2025
- PERCENT COMPLETE: 2%

BUDGET

- TOTAL PROJECT FUNDING: $2,501,872
- INDUSTRIAL COST SHARE: $507,182
- YEAR 1 FUNDING: $749,813

PARTNERS

- WM INTERNATIONAL ENGINEERING
- ILLINOIS INSTITUTE OF TECHNOLOGY
- ARGONNE NATIONAL LABORATORY
- DIVERSIFIED CPC INTERNATIONAL

BARRIERS AND TECHNICAL TARGETS

TARGETS

- Commission a **high pressure injection system** for PROPANE-DME mixtures.
- Lower the fuel consumption of baseline SI 2021 2.0L (192 gCO2/km) to **126 gCO2/km**.
- Transition current EPA 2021 Tier 3 - LEV III ULEV 50 to **EPA 2026 Tier 3 - LEV III ULEV 30**

BARRIERS

- Operating at high pressures leads to premature wear.
- Fuel compressibility leads to unstable injections, compromising the ability to operate with multiple injections per cycle.
- Unstable combustion at low load with higher propane blends due to higher auto-ignition threshold.

RELEVANCE

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IMPACT

- In order to achieve the project goal of 34% GHG reduction, we need to develop a fast-acting direct injection fuel system to be able to inject fuel at or near TDC to facilitate mixing controlled CI.
- The system needs to demonstrate seamless operation across a range of propane-DME blends while adhering to the performance metrics of DI systems:
  - excellent atomization
  - adequate penetration of jets
  - accurate fuel metering and timing
  - multiple injections.
- The injection system needs to offer system durability that is on par with that of traditional Diesel fuel systems.

OBJECTIVES

INJECTION PERFORMANCE TARGETS

Injection pressure capability:	2000bar
Engine speed:	5000rpm
# of injections at rated speed:	5
Maximum dwell btw injections:	0.5ms
Minimum fueling capability:	1mg/stroke
Maximum fueling at 2ms command:	100mg/stroke
Max deviation below 20mg:	±0.2mg/stroke
Max deviation above 20mg:	±0.5mg /stroke

INJECTION DURABILITY TARGETS

8hr cycle: 30min idle; 6.5hr cruise (2000rpm, 1500bar); 1hr peak power (3500rpm, 2000bar).
Repeat 4 times (5x8=40hr total) operation.
Run calibration map and inspect.
Repeat 5 times (200hr total).

ENGINE TARGETS

Performance Goals

Case	Description	Comb Mode	gCO_2	Peak BTE	Goal
1	100% propane	SI	171	31.4%	-
2,3,4	projection with renewables	SI	126,111,111	31.4%	-
5	50% propane, 50% DME	CI	126	42.9%	milestone
6	20% propane, 80% DME	CI	126	42.9%	milestone
7	20% propane, 80% DME	CI	111	48%	milestone
8	projection with renewables	CI	111	42.9	-

Emission standards: Tier 3 – Bin 20

MILESTONES

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Milestone	Year 1	Descritiption	status
Fuel system model complete	Q1	System description. Complete the electro-hydraulic fuel system modeling. Operating instructions. Calibraton maps.	80% 20% 10% 0%
Performance fuel bench complete	Q2	Bench design. Functional validation with Propane-DME. Runs with base hardware	50%
Durability fuel bench complete	Q3	Bench design. Functional validation with Propane-DME. Installation at ANL	
Fuel system design complete	Q4	Modeling of fuel system shows 2000bar, 0.5ms dwell Complete manufacturing drawings Kick-off procurement	
Modeling supports efficiency and CO2 targets	Q4/GO-NG	Engine Modeling to match baseline Diesel data Extend Engine modeling to Propane-DME mixtures Modeling demonstrates 126gCO2/km and 42.9% BTE	

APPROACH

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- Propane and DME can be used to substantially reduce the GHG emissions. Introduction of DME into propane enables tapping into the high efficiency of the CI combustion process.

- We are proposing the development of a fast response direct injection system with a configuration as illustrated here.

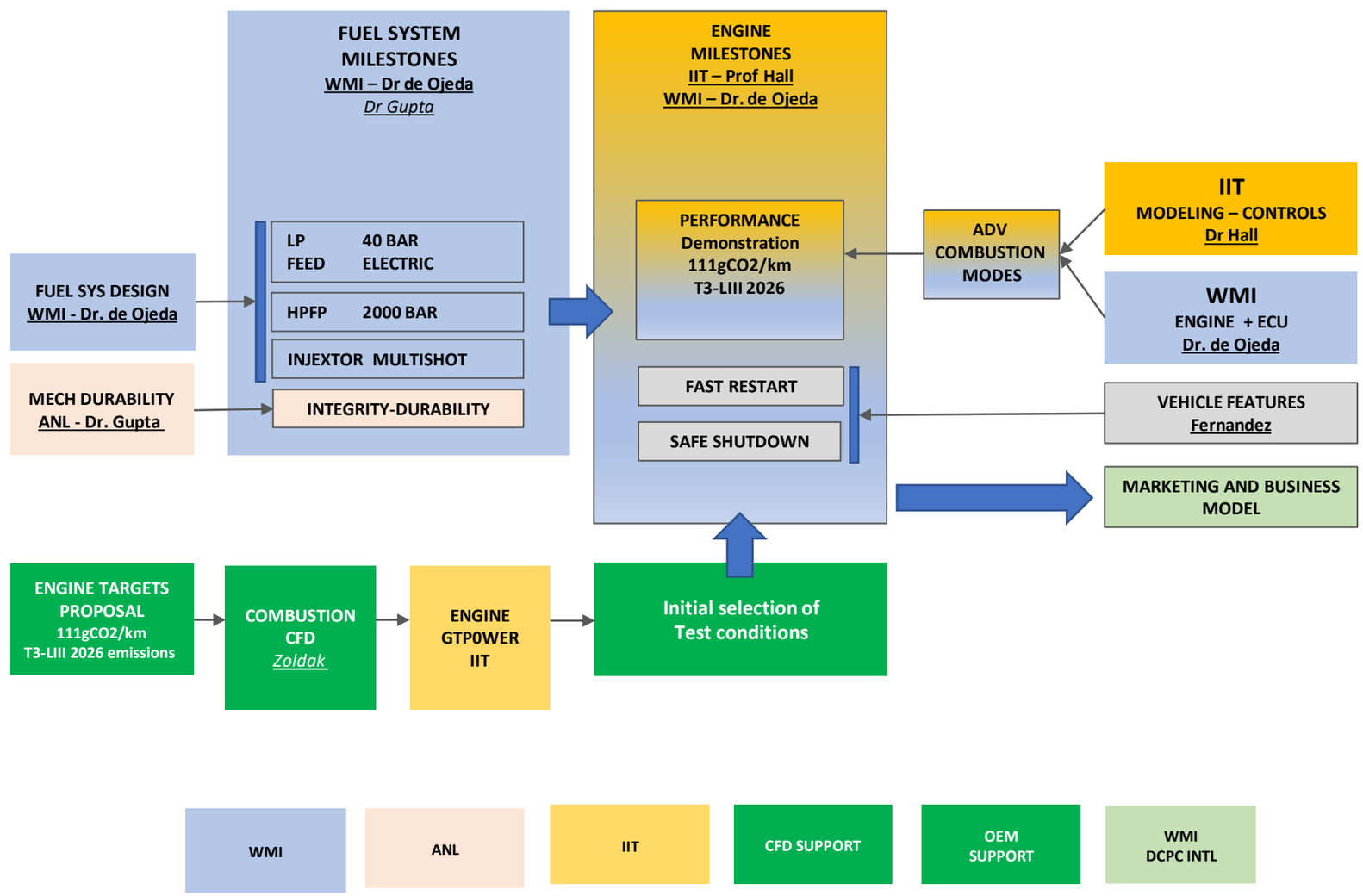
- APPROACH IS BASED ON:

❖ Strong partnership

❖ Modeling of Fuel Injection System
❖ FIS test and validation
❖ FIS durability validation

❖ Modeling of Engine
❖ Optimization of fuel mixtures
❖ Engine testing

❖ Corroborate efficiency goals
❖ Corroborate commercial goals



TECHNICAL ACCOMPLISHMENTS

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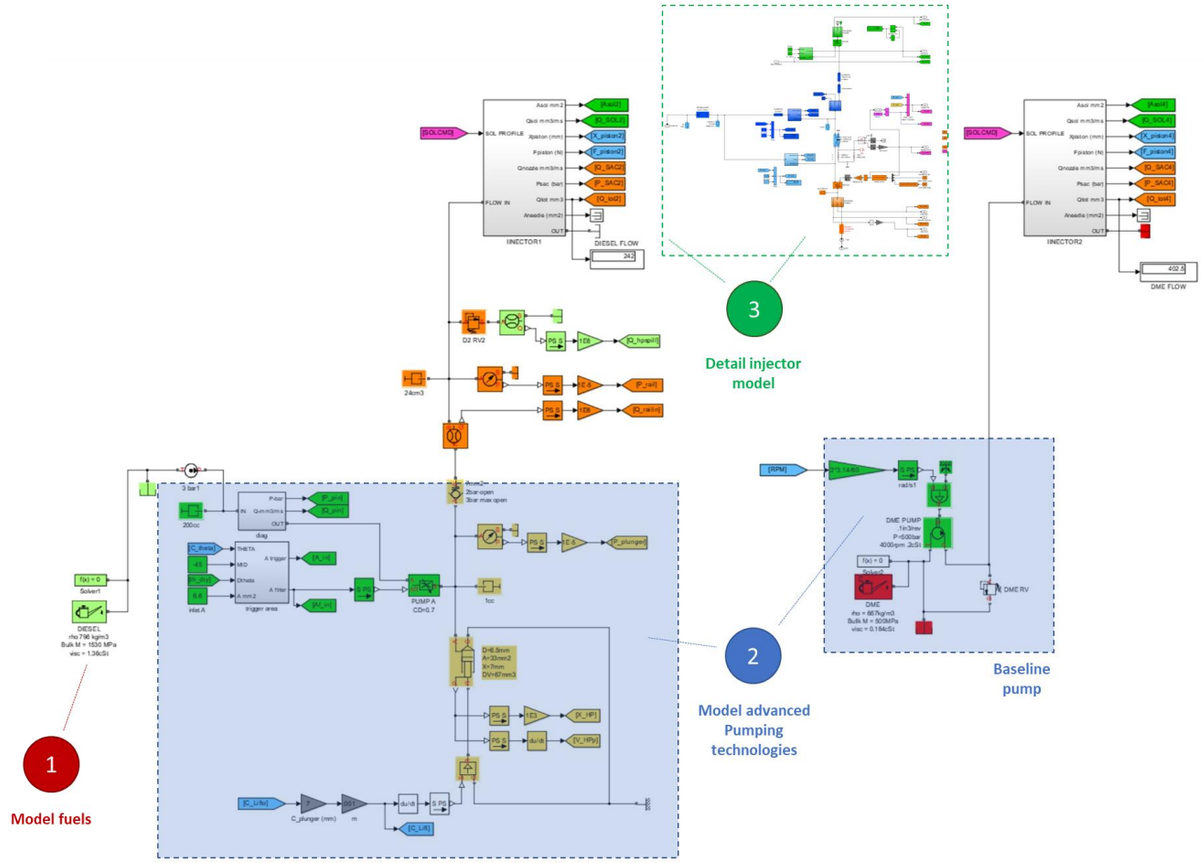
- STARTED FUEL SYSTEM MODELING AND DESIGN

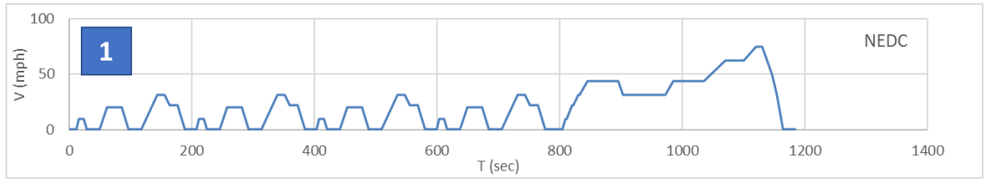
❖ Identified focus areas:
❖ Fuels (compressibility, LHV, density…)
❖ HP pump (flow, efficiency)
❖ Injector (flow, control)



- STARTED BASELINE FTP ESTIMATIONS

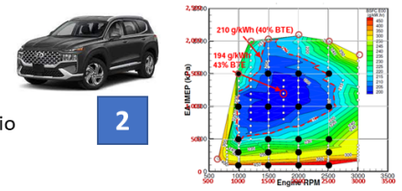
✓ Modeling tools capable to predict cycle CO2 performance numbers

NEDC Cycle



NEDC CALCULATIONS				
Total dist	km	10.9		
Total fuel	g	619		
Tot fuel	g/km	56.7		
	mpg	34.20		
LHV	MJ/kg	43	43	43
CO2	g/MJ	73.6	73.6	73.6
CO2	g/km	179		

INPUTS:
1. Cycle Velocity vs. time
2. Vehicle characteristics (W, Cd-A, Cr)
3. Fueling Map, Mf(N,TQ)
4. Six-speed transmission and Axel Ratio



AXLE RATIO	3.2
GR #	GR
1	3.54
2	1.91
3	1.18
4	0.9
5	0.74
6	0.63

4

HYUNDAI specs:		combined	hwy	city
Fuel	L/100km	6.8	5.6	8.8
rho	kg/m3	820	820	820
Fuel	g/km	55.8	45.9	72.2
Fuel	mpg	34.7	42.2	26.8
CO2	g/km	176	145	228
CO2 NEDC reported		176		

✓ Calculated **179g/km** vs published **176g/km** provides good match with respect to HYUNDAI cert data

TECHNICAL ACCOMPLISHMENTS

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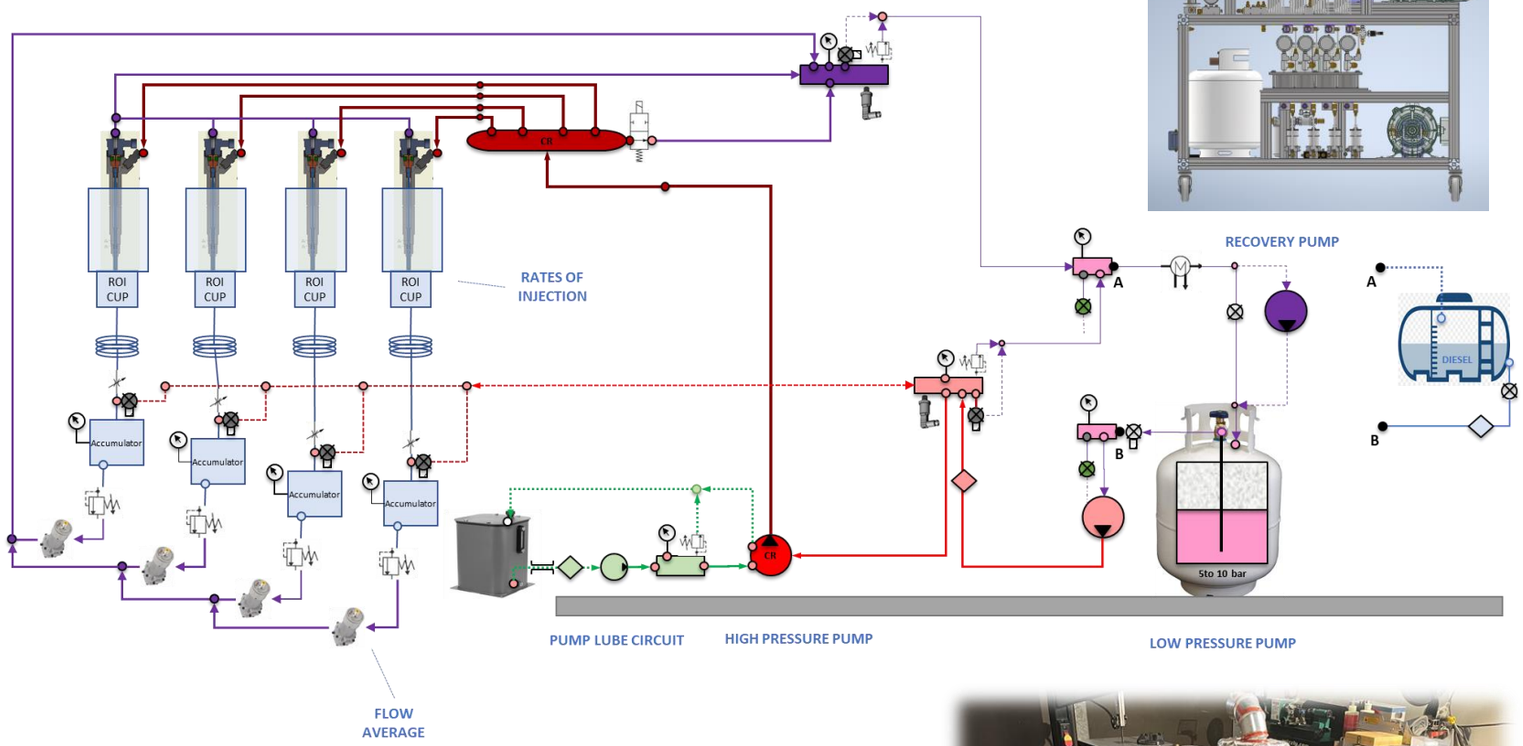
- FUEL CALIBRATION BENCH DESIGN

✓ CAD rendering nearly complete
✓ Some parts are procured

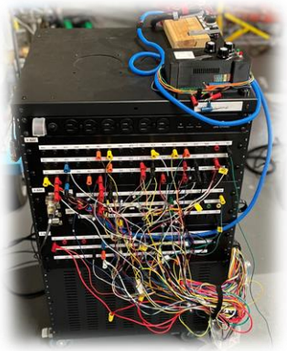


ENGINE INSTALLATION

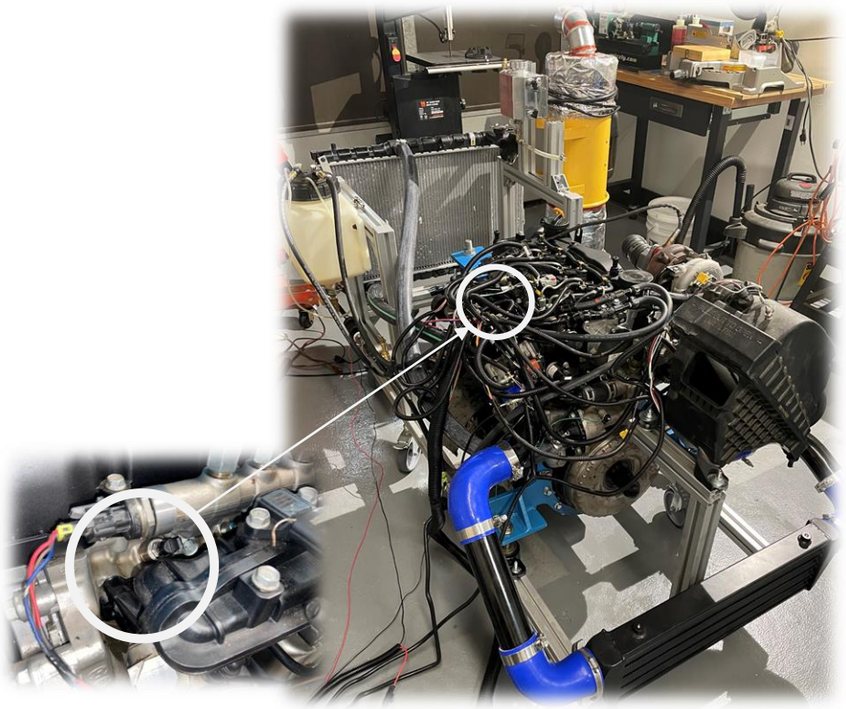
✓ Engine on cart
✓ Harness in place
✓ connected to OPEN ECU
✓ Installed cylinder pressure transducers

Next activities will be:

❖ SI installation
❖ Configuration to new fuel supply



Open ECU and breakout cart



Cylinder pressure sensor on head

COLLABORATIONS

WM INTERNATIONAL ENGINEERING
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WM INTERNATIONAL

- Program Management
- Fuel System Modeling and Design and Manufacturing
- Fuel System Testing and Validation
- Engine Build, Testing
- Technical and Commercial Targets Assessment

ILLINOIS INSTITUTE OF TECHNOLOGY

- Engine Modeling and performance predictions
- Engine Testing at IIT's Advanced Engine Control Laboratory

DIVERSIFIED CPC INTERNATIONAL

- Supply Fuel
- Fuel storage, safety, and handling procedures

ARGONNE NATIONAL LABS

- Spray characterization
- Durability tests on fuel injection equipment
- Tribology analysis and reporting

FUTURE WORK

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2022-2023 BUDGET PERIOD 1 ACTIVITIES

DESIGN AND PROCURE NEW INJECTION SYSTEM

- Complete electro-hydraulic MODEL for the new fuel mixtures — June 2022
- Complete manufacturing drawings and send for procurement — Aug 2022

FUEL INJECTION PERFORMANCE BENCH

- Perform validation runs with Diesel — June 2022
- Perform calibration maps with PROPANE-DME using baseline fuel system — Sep 2022
- Start calibration maps with PROPANE-DME using advanced fuel system — Feb 2023

FUEL INJECTION DURABILITY BENCH

- Start build after development bench is used and vetted — Sep 2022
- Deliver bench to Argonne — Nov 2022

ENGINE MODEL

- Complete Diesel benchmark — June 2022
- Complete PROPANE-DME benchmarks — Feb 2022
- Validated feasibility of CO2 targers — Feb 2022

ENGINE PREP

- Complete instrumentation and vetting with Diesel — July 2022
- Initial PROPANE-DME runs with baseline hardware — Oct 2022
- Install new fuel system — March 2022

SUMMARY

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PROJECT KICK-OFF

- ✓ Project officially kicked of on 30 March 2022
- ✓ DOE-Team kick-off meeting held on 19 April 2022

INITIAL ACCOMPLISHMENTS

- ✓ Fuel system model initiated:
  - ➢ begun detailed model of fuel system
  - ➢ optimizing the fuel system design for use with PROPANE-DME

- ✓ Fuel bench design initiated:
  - ➢ Systems design nearly complete.
  - ➢ Selection of most components made. Expect start of build in May 2022.

- ✓ Engine Build:
  - ➢ Engine placed on cart and connected to open-ECU platform.

- ✓ Engine Modeling:
  - ➢ Provided test data for model verification.
  - ➢ Model build start expected in May 2022.
  - ➢ Corroborated FTP model CO2 estimates with engine cert data.