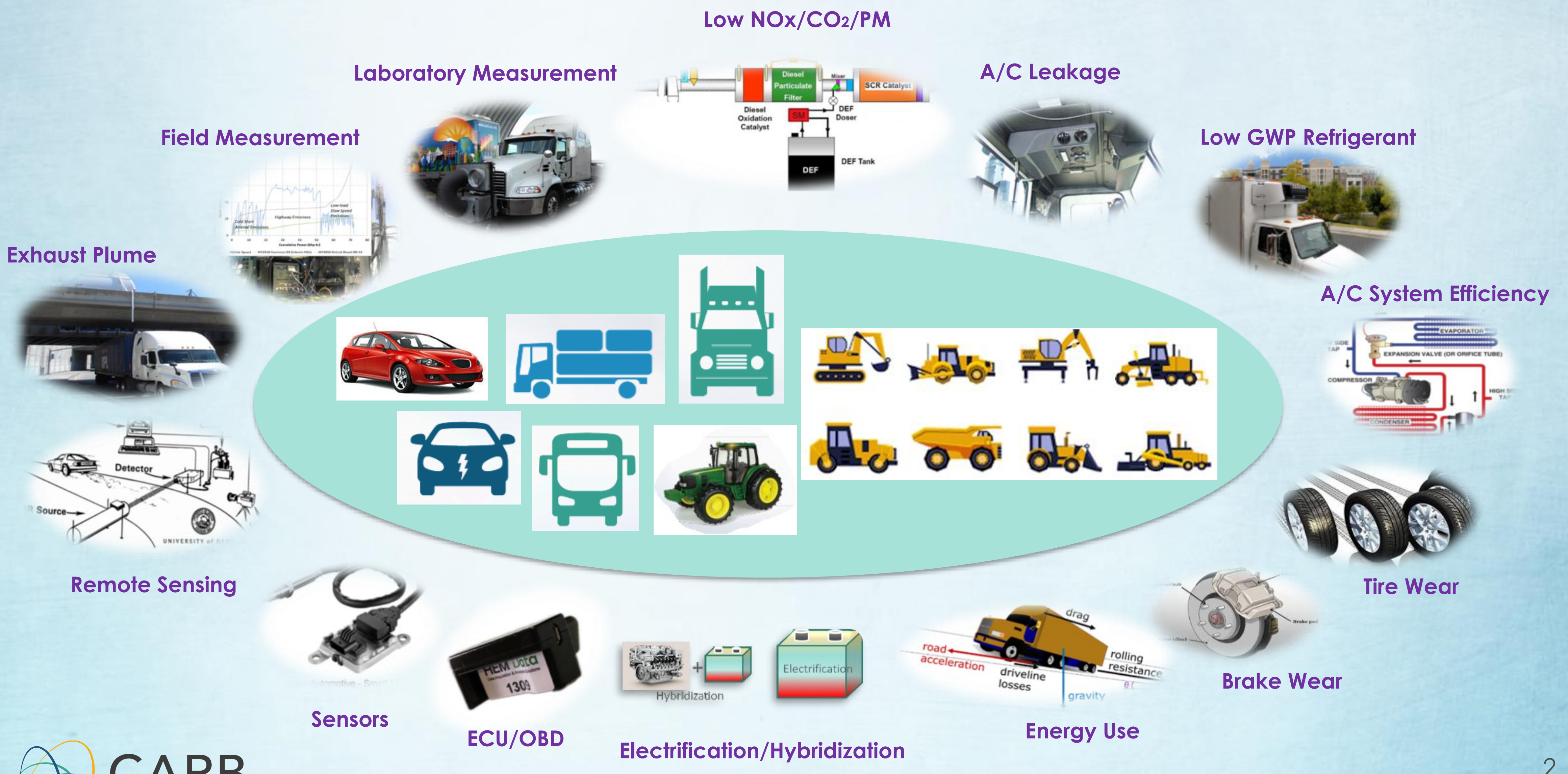
CALIFORNIA
AIR RESOURCES BOARD

CARB Off-Road Research

March 23, 2021

Mobile Source Emissions Research



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Today’s Presentations

- Off-road projects
  - Next Tier Off-Road Diesel Low-NOx Aftertreatment Technology Optimization – Yi Tan
  - Agricultural Equipment Activity Data Collection - Yi Tan
  - Activity Data of Off-Road Engines in Construction – Qi Yao
  - Off-Road Hybridization and Electrification – Hari Perugu

Next Tier Off-Road Diesel Low-NOx Aftertreatment Technology Fabrication and Optimization

- Yi Tan -

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Background

- Last updated off-road diesel standards 15 years ago (Tier 4 in 2005)
- Lag behind on-road diesel engine emission standards
- Completed Tier 4 baseline engine testing project (18RD006)

Tier 4 emission standards — Diesel engines up to 560 kW, g/kWh (g/bhp-hr)						
Engine Power	Year	CO	NMHC	NMHC+NOx	NO_x	PM
kW < 8 (hp < 11)	2008	8.0 (6.0)	-	7.5 (5.6)	-	0.4 (0.3)
8 ≤ kW < 19 (11 ≤ hp < 25)	2008	6.6 (4.9)	-	7.5 (5.6)	-	0.4 (0.3)
19 ≤ kW < 37 (25 ≤ hp < 50)	2008	5.5 (4.1)	-	7.5 (5.6)	-	0.3 (0.22)
	2013	5.5 (4.1)	-	4.7 (3.5)	-	0.03 (0.022)
37 ≤ kW < 56 (50 ≤ hp < 75)	2008	5.0 (3.7)	-	4.7 (3.5)	-	0.3 (0.22)
	2013	5.0 (3.7)	-	4.7 (3.5)	-	0.03 (0.022)
56 ≤ kW < 130 (75 ≤ hp < 175)	2012-2014	5.0 (3.7)	0.19 (0.14)	-	0.40 (0.30)	0.02 (0.015)
130 ≤ kW ≤ 560 (175 ≤ hp ≤ 750)	2011-2014	3.5 (2.6)	0.19 (0.14)	-	0.40 (0.30)	0.02 (0.015)

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Tier 4 Baseline Testing

- John Deere 6068
  - 6.8L, I-6 (dual series turbo)
  - 187kw (meas. 189) nominal rating at 2200 rpm
  - 1026 Nm (meas. 1043) peak torque at 1600 rpm
  - 800 rpm idle
  - DOC+DPF+SCR
- Stock AT system – de-greened only
- Measured criteria pollutants, CO_2, and other unregulated species
- Will be used for low NOx demonstration

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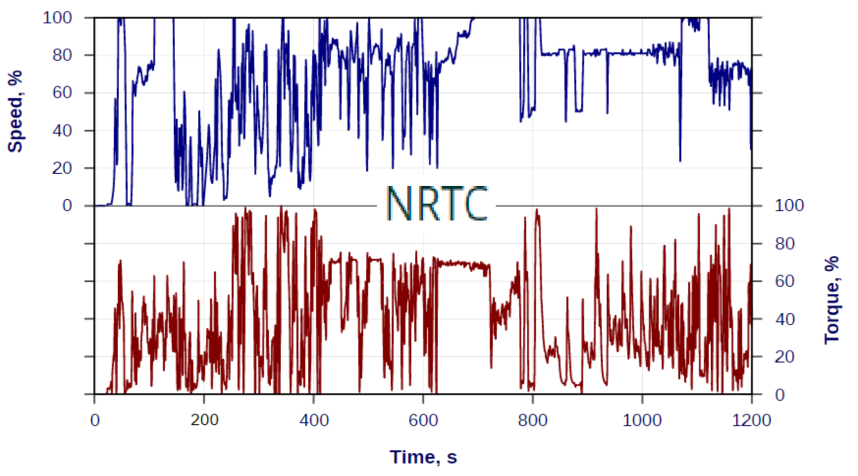
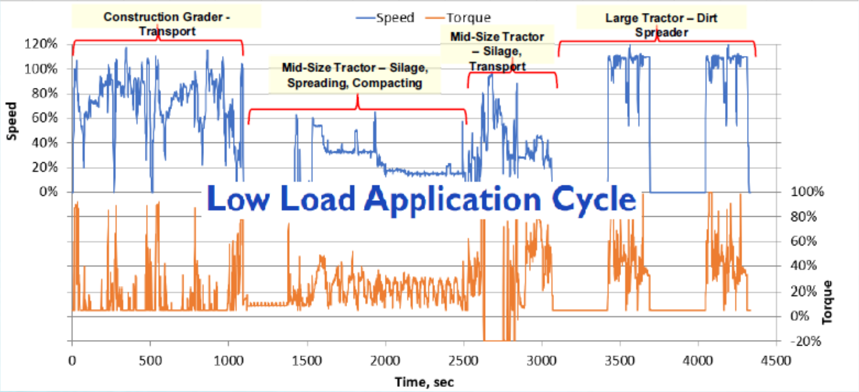
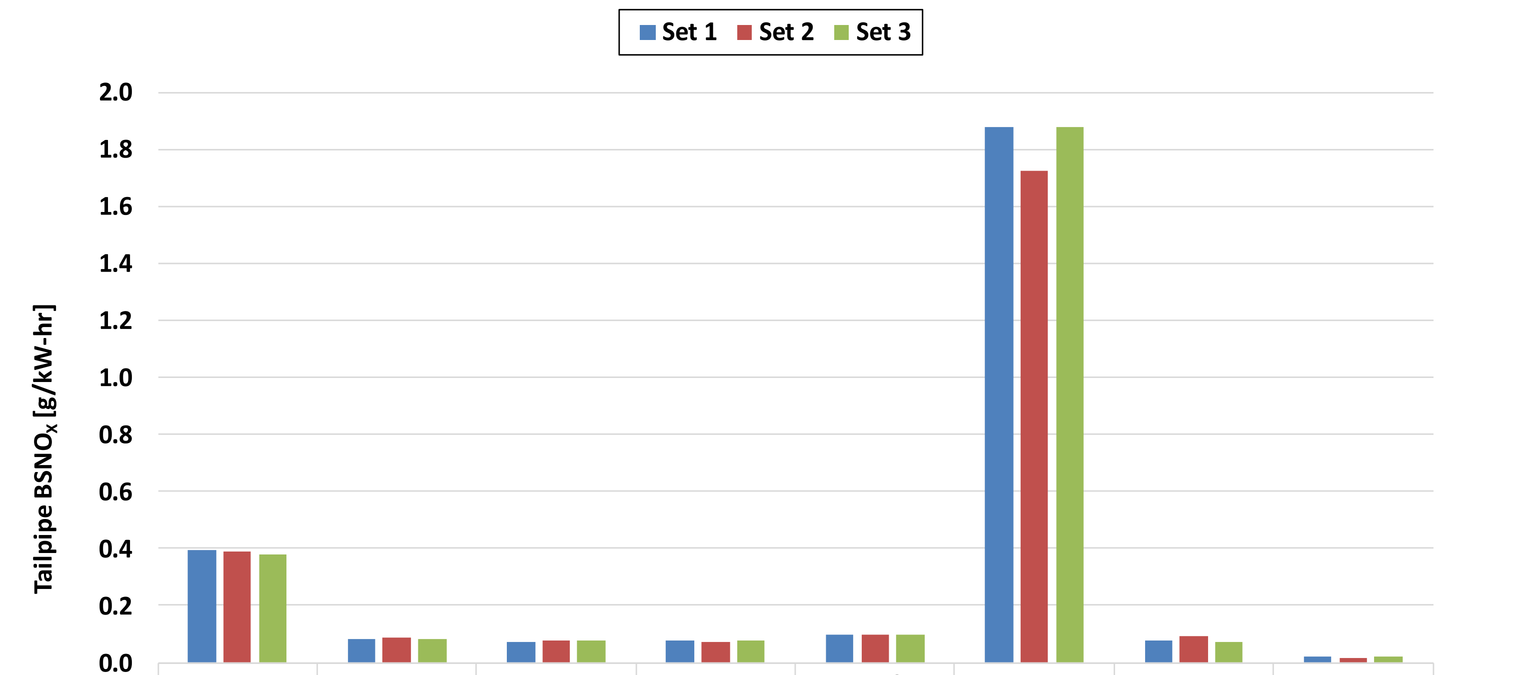
Preliminary Results of Tier 4 Baseline Emissions







	NRTC: Cold	NRTC: Hot 1	NRTC: Hot 2	NRTC: Hot 3	NRTC: Composite	LLC	RMC C1	RMC D2
Set 1	0.393	0.081	0.073	0.075	0.096	1.878	0.074	0.019
Set 2	0.389	0.085	0.078	0.073	0.100	1.723	0.094	0.017
Set 3	0.378	0.083	0.076	0.078	0.098	1.878	0.069	0.018

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Objectives

- Design, procure, age, and optimize advanced NOx and PM aftertreatment technologies for incorporation on a new Tier 4 off-road diesel engine
  - Reduce NOx emissions by 90 percent and PM emissions by 75 percent below Tier 4 final standards
  - Reduce GHG emissions by 5 – 8.6 percent
  - Provide CARB with an optimized low-NOx and low-PM configuration to support future Tier 5 standards

Tasks and Timeline

- Tasks
  - Engine and Test Cycle Selection and Baseline Testing – Already Complete
  - Leverage current Tier 4 baseline test results (contract 18RD006)
  - Development and Calibration
    - Simulation and Procurement – Simulation complete, working on procurement
    - Engine Calibration
    - Aftertreatment Integration
  - Development Aging
  - Demonstration Testing of Aged Systems
- Timeline
  - Kick-off: June 2020
  - Final report: May 2022
- Project partners
  - SCAQMD, MECA, US EPA

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Agricultural Equipment Activity Data Collection

- Yi Tan -

Background

- Diesel engines commonly used in Ag industry
  - >50% of CA agriculture equipment is in San Joaquin Valley (SJV)
  - 14% of NO_x in SJV from farm equipment
- Accurate data on agricultural equipment is critical to develop emissions inventories.
  - Improve air quality
  - Develop effective incentive strategies for the SJV
- More information is needed on in-use activity patterns for ag equipment compare to other off-road equipment

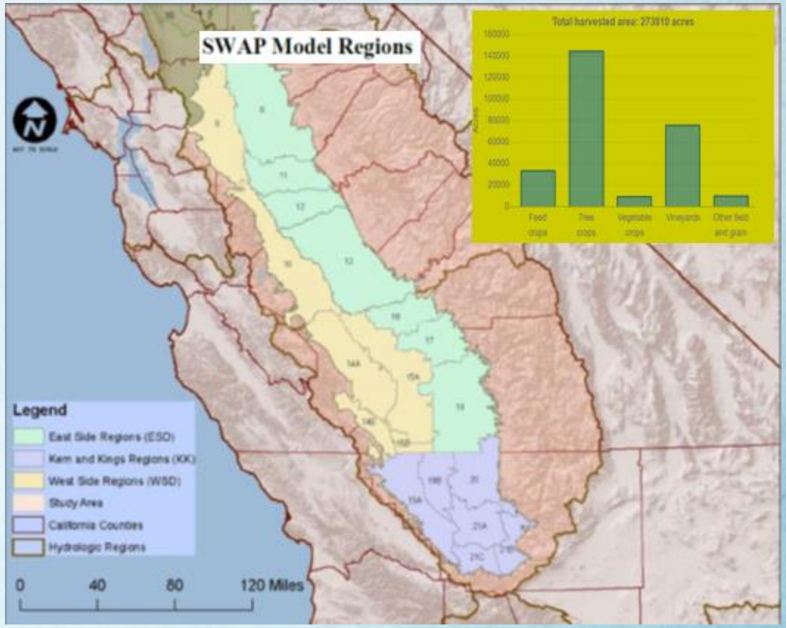
Objectives

- Characterize how agricultural engines in the SJV operate under actual working conditions, including their activity parameters (e.g., engine speed, torque, and fuel rate) and maintenance frequency, type, and cost.
- Collect accurate real-world data from agricultural equipment to improve the emission inventory, and to inform policies, incentive programs and the development of future off-road engine emission standards.



Targeted Crop Types in Consideration of Soil Type and Farm Size

Group 1		Group 2	
Tree/Orchard/Nut	Examples	Field and Row Crops	Examples
Citrus	Orange, Lemon, etc.	Row Crops	Corn, Cotton
Nut Crops	Pistachio, Almond, Pecan	Vegetables	Carrot, Potato
Tree Fruit	Apple, Pear, Stone Fruit, Cherry	Grains (rice, oats)	Rice, Oat, Wheat
Grapes	Table, Raisin	Hay, Forage, Pasture	Grass, Hay



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240 Engines will be Logged for a Full Year

Engine Size	Group1 Tree/Orchard/Nut		Group 2 Field and Row Crops	
	Tier 0-1-2	Tier 3-4	Tier 0-1-2	Tier 3-4
25 ≤ hp < 75	11	15	11	16
75 ≤ hp < 300	21	33	21	33
300 ≤ hp < 600	8	12	8	11

Data Needs	Purpose	Engine Parameters
Engine load	Emission inventory; emission standards	Engine speed, torque values
Engine fuel economy	Emission inventory; incentive programs	Engine fuel rate, Diesel Particulate Filter (DPF) fuel rate
Engine performance	Emission standards	Engine intake air mass flow rate, intake manifold temperature, intake manifold pressure, engine oil temperature, engine coolant temperature, engine exhaust gas recirculation mass flow rate
Aftertreatment performance	Emission standards	DPF active regeneration status, Selective Catalytic Reduction (SCR) inlet temperature, SCR outlet temperature, SCR inlet NOx concentration, SCR outlet NOx concentration, Diesel Exhaust Fluid (DEF) dosing quantity, DEF tank volume
Malfunction and maintenance	Emission standards; incentive programs	Malfunction Indicator Lamp (MIL) status, Suspect Parameter Number, Failure mode identifier, occurrence count

The study also includes a rental equipment use survey and the data collection of 40 rental equipment operating in SJV.

Project Status and Timeline

- Project status
  - Collaboration and data collection plans – complete
  - Initial contacts to candidate participating farms/rental companies – ongoing
  - Full-scale data logging started in 2021 – ongoing
  - Weekly progress update meeting
- Final report: Fall 2023
- Project partners
  - Agricultural Tech Group
  - SJV APCD
  - U.S. EPA

Activity Data of Off-Road Engines in Construction

- Qi Yao -

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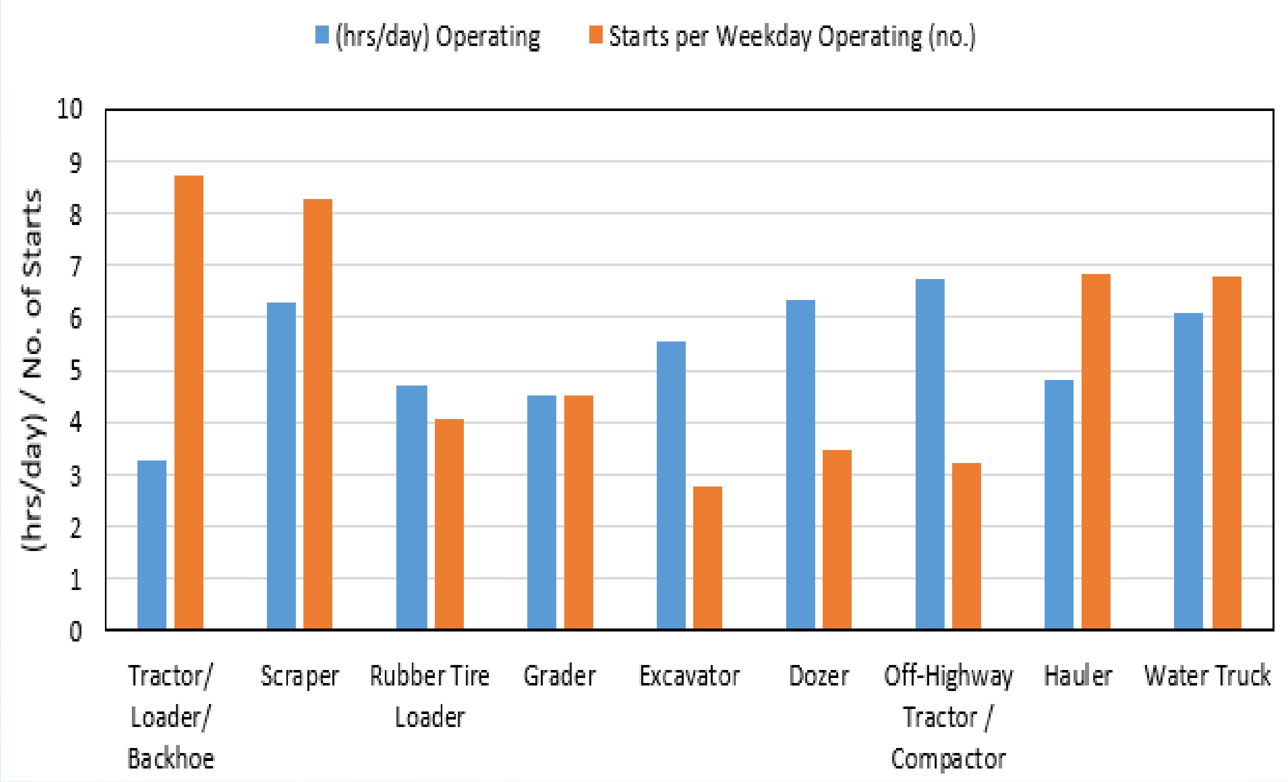
Objectives

- Characterize the activity profiles (e.g., operation duration on an average working day, load factor variation during operation, and exhaust temperature) for heavy-duty off-road equipment used for construction or other off-road purposes.
- Contribute to off-road equipment emission certification test cycle design and updates.
- Understand real-world NOx emission for typical types of off-road equipment and engines using NOx sensor readings

Equipment Type
Rubber Tired Loaders
Backhoes/Tractors/Loaders
Water Truck
Scraper
Dozers
Excavator
Grader
Cranes
Rubber Tired Dozers
Compactors/Off-Highway Tractors
Hauler
Total

Preliminary Results – Engine Hours and Starts



- Operational time varied from about 3 to 7 hours per day, depending on the category.
- The off-highway tractors had the highest operational time per day, followed by the dozers and the scrapers
- The starts/day varied from less than 3 to nearly 9, depending on the category.

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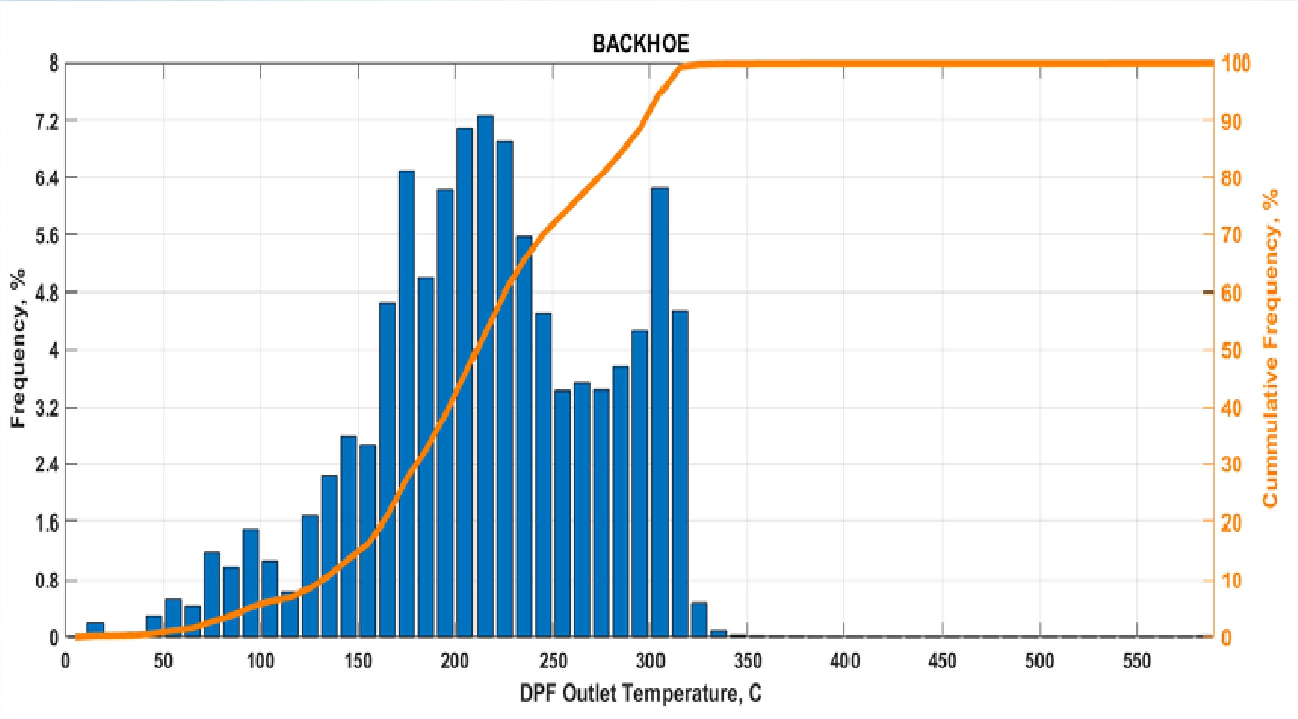
Preliminary Results – Exhaust Temperature



- DPF outlet temperature is below 200°C for about 50% of the backhoe operation
- SCR efficiency for this category could be limited for a significant portion of the operational cycle for equipment in this category

Example: assess effectiveness of aftertreatment controls for backhoe

Off-road Hybridization and Electrification

- Hari Perugu -

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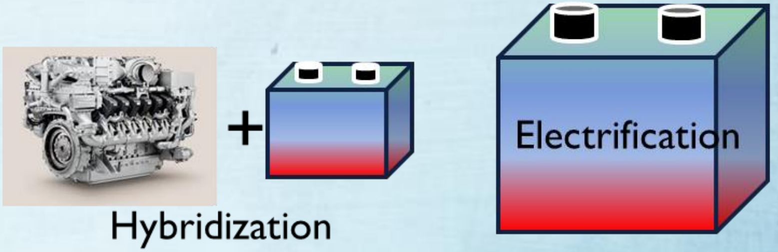
Objectives

- Characterize activities, duty cycles, and energy demands of off-road equipment in different applications
- Assess the current trends toward hybridization and electrification
- Determine off-road applications that could feasibly be partially or fully electrified in the near future
    - Maximize climate and air quality benefits
    - Technically and economically viable



Hybridization

Duty Cycles

Infrastructure

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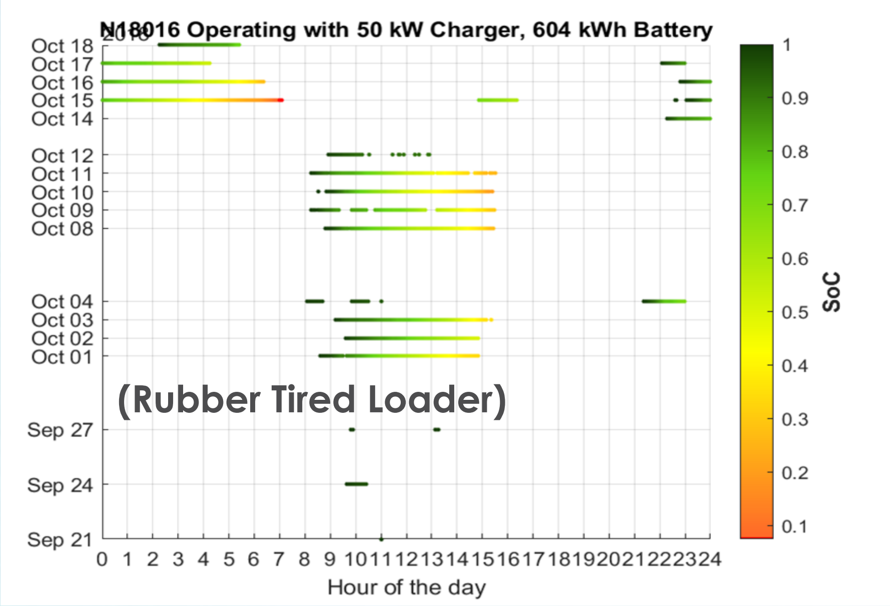
Technical Approaches

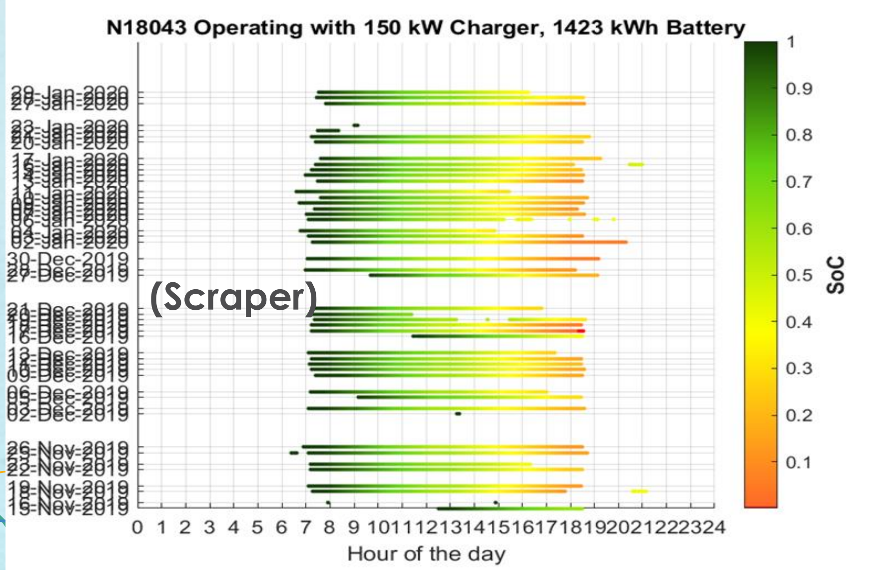
- Evaluating existing off-road technologies in various applications and analyzing their contributions to GHG and criteria pollutant emissions
- Investigating emerging engine technologies and applications in the market
- Identifying current technology engine size and application sectors that can potentially be hybridized or electrified
- A cost-benefit analysis which examines in detail the benefits of GHG and criteria pollutant emissions reduction from hybridizing/electrifying off-road equipment

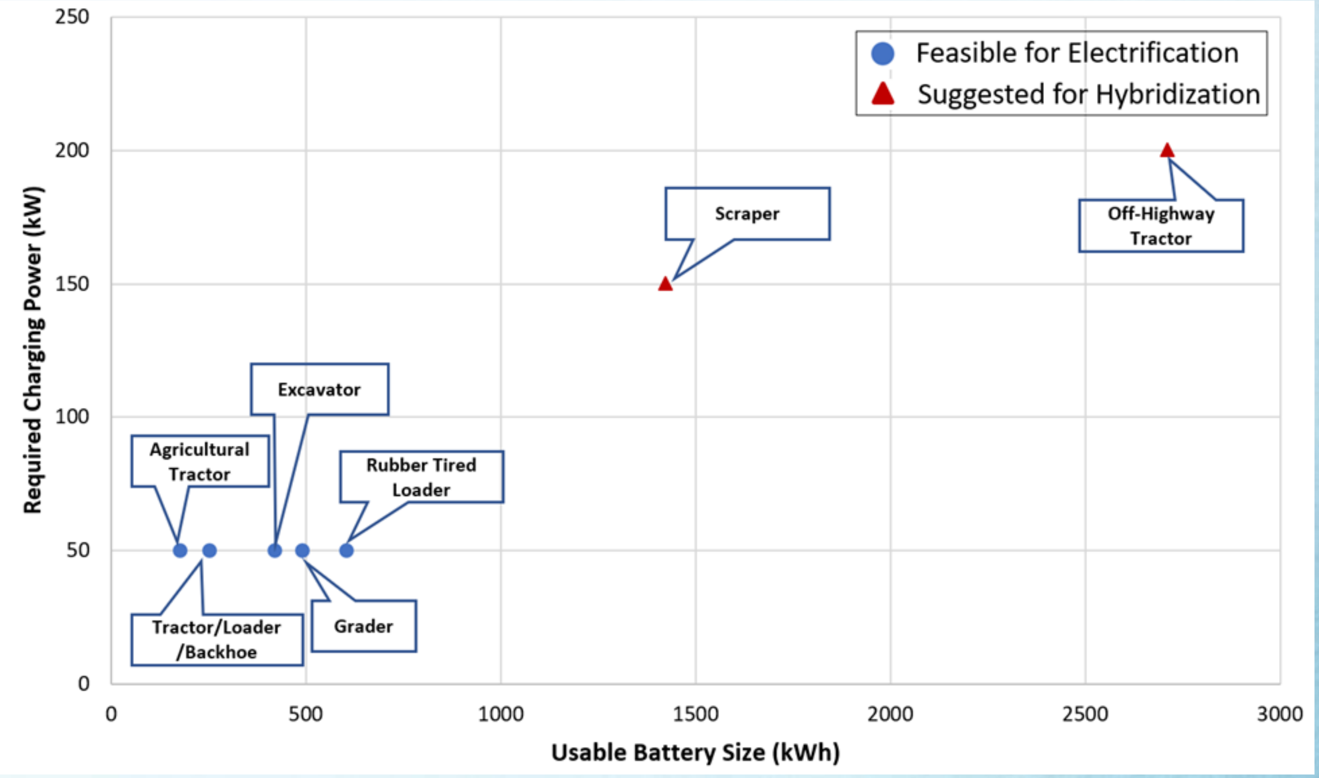
Preliminary Findings

- Off-road equipment inventory and market share analysis
  - Reviewed nearly 100 technical publications related to electrification of construction and agricultural equipment.
  - Reviewed technical specifications of currently available and planned for near future construction and agricultural equipment
  - Largest barriers for electrified off-road vehicles in the current market are incremental cost, and lack of user acceptance
- Off-road hybridization/ electrification feasibility analysis
  - All major construction OEMs are developing electrified products
  - Productivity is the main driver of these technologies
  - Battery technology remains a major obstacle to higher levels of deployment
  - Urban zero-emission zones and regulations could be catalyst for electrification
  - Identified vocational equipment that could be electrified or hybridized

Electrification/Hybridization Feasibility







Cost-effectiveness Analysis

- Emissions and cost effectiveness of incentive funding are calculated:
  - For each equipment type, for each model year in each calendar year
  - For individual emissions of NOx, PM2.5, and CO2, as well as combined emissions
  - For replacing a single piece of equipment as well as the whole population
- Demonstrate how incentive programs can be tailored to help CARB achieve the GHG reduction and air quality improvement goals

Remaining Tasks and Timeline

- Remaining tasks
  - Emission impact analysis updates
  - Cost effectiveness analysis updates
  - Recommendations for future data collection
- Timeline
  - Final report by late 2021

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Questions on Off-Road Projects and Contact Information

- Questions
  - Today's presentations
  - CARB mobile source emissions research
- Contact information
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