



Potential Emission Benefits of Zero Emission Technology Adoption Scenarios in Off-Road Equipment

2023 CRC Workshop
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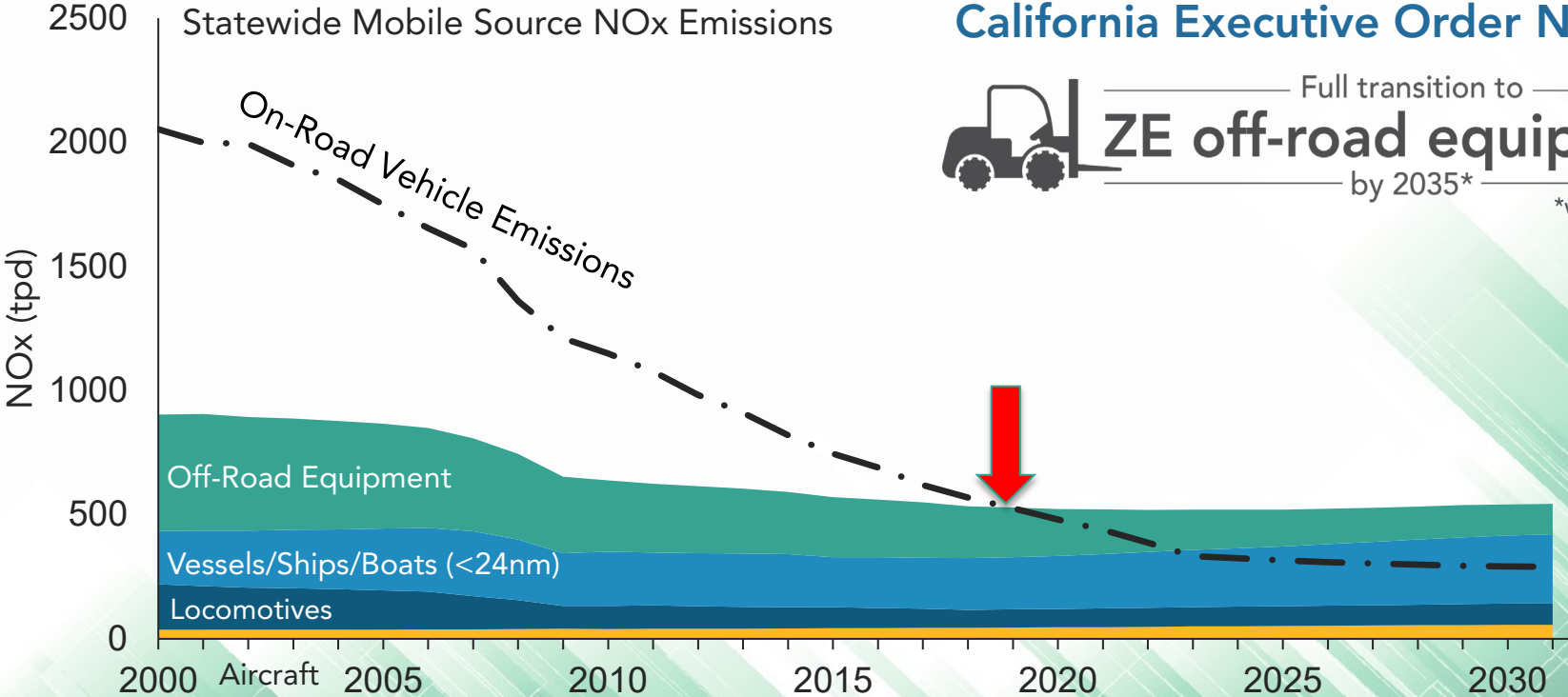


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Zero-Emission Off-Road Equipment



Growing Importance of Off-Road



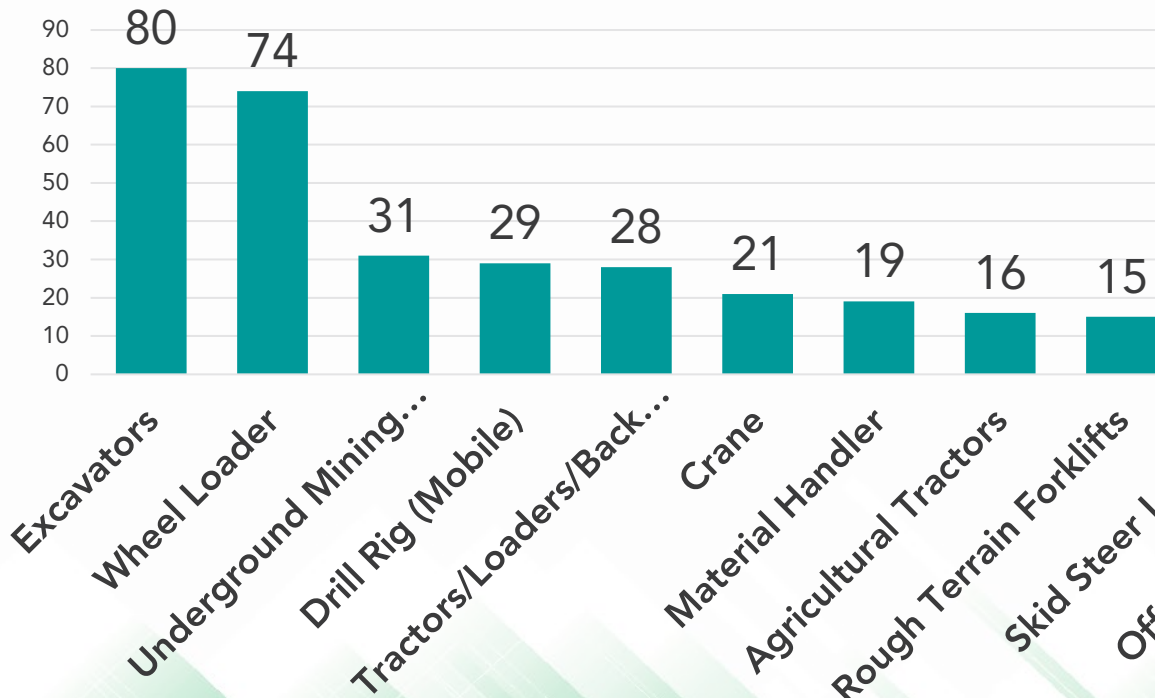
Presentation Outline

- Review currently available ZE technologies for off-road equipment (ORE) sectors
- Develop framework for evaluating high-ZE-potential off-road sectors and equipment
- Discuss the critical role of alternative charging solutions for heavy-duty equipment
- Demonstrate potential emission benefits of the ZE equipment adoption



Over 500 models of ZE Off-Road Equipment

Count of ZE ORE models (n>10)



Zero-Emission and Hybrid Off-Road Vehicle and Equipment

- Eliminate 100% of downstream criteria pollutants and greenhouse gas emissions
- Needed to achieve California's Executive Order N-79-20
- Lower California's energy import needs, and increase energy security

Introduction

Off-road equipment (ORE) sector includes a broad spectrum of equipment and vehicle types, such as construction, agricultural, industrial, cargo handling equipment, locomotive, marine vessels, etc. Each ORE sector has unique operational characteristics and mechanical features.

ORE manufacturers have put a significant effort into implementing various zero-emission technologies into their conventionally fueled equipment. Many demonstration projects are going on and increasingly commercially available. This page presents the zero-emission off-road equipment cases (zero-emission ORE) currently available in the market or under testing demonstration stages. ARB aims to achieve the following goals by sharing the list.

- Compiling and sharing a list of off-road equipment manufacturers' current efforts for zero emissions
- Providing a reference for the electrification potential in off-road sectors

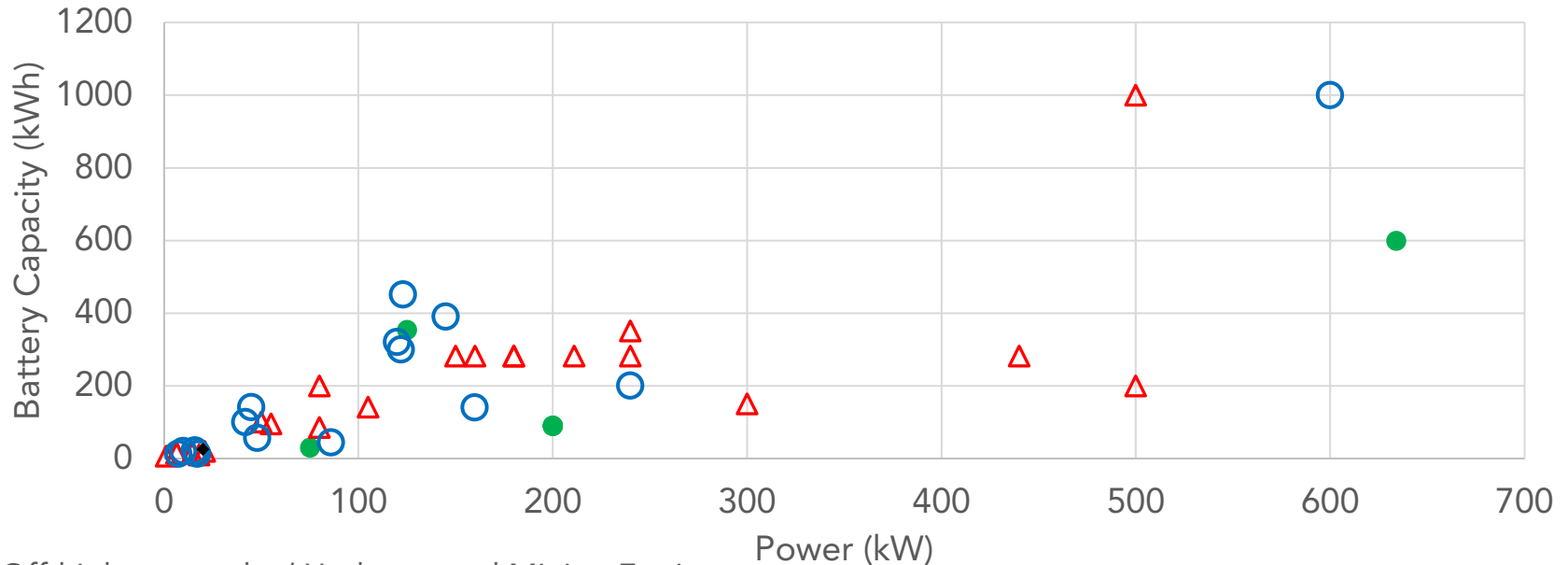
Electric Construction and Mining Equipment

Vehicle Type	Make	Model	Description
Excavators	Pon / Caterpillar	323 Z-Line	Electric 16-Ton Excavator
Excavators	Pon / Caterpillar	320 Z-line	Electric 25-Ton Excavator
Excavators	Pon / Caterpillar	310 Z-line	Electric 12-Ton Excavator
Excavators	Volvo CE	EK2	World's first fully-electric compact excavator prototype, according to the manufacturer.
Excavators	Volvo CE	ECR25	Trench digging equipment. Operating time is up to 4 hours
Excavators	XCMG	XE35U-E	Cummins BMS-7E battery modules
Excavators	Suncar HK	TB260e	
Excavators	Suncar HK	TB1140e	

- This is based on a limited market research and includes commercial and demo battery-electric, H2FC, & grid-connected models
- 50 ORE types with 64 models were excluded from the ZEE list (<https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road-1>)

Battery Storage vs. Power of Current ZE ORE

- Existing ZE options provide a picture of the energy storage needed for different types and sizes of applications



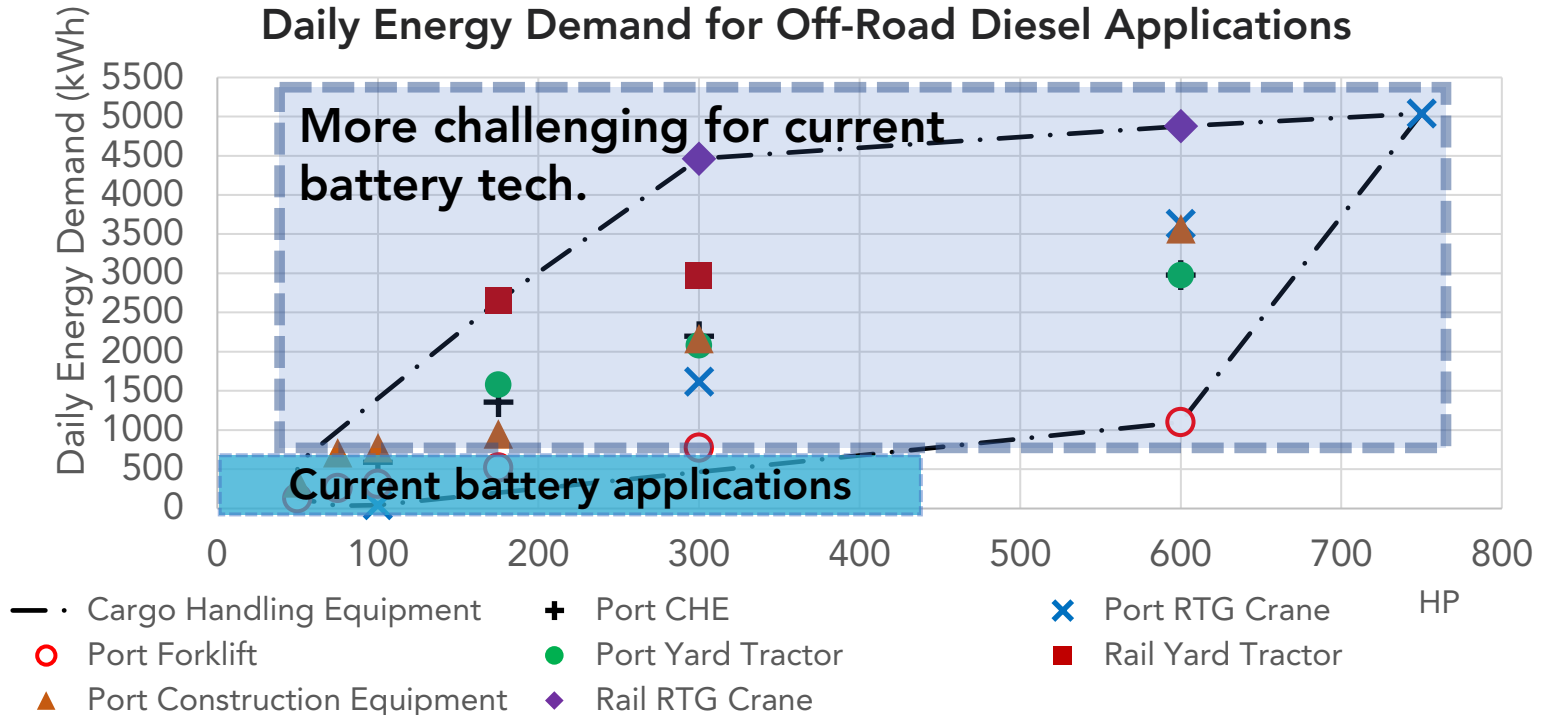
- Off-highway trucks / Underground Mining Equipment
- ▲ Tractors/Loaders/Backhoes/Wheel loaders/Rubber tired loaders/Rough terrain forklifts/Telehandlers/Forklifts
- Excavators / Drill Rigs
- ◆ Pavers/Rollers/Skid steer loaders

Forecasting ZE Adoption

- Forecasting growth of ZEE in off-road sectors needed for:
 - ZE infrastructure and energy planning
 - Understanding the replacement of diesel market segments
 - Inform incentive and demonstration programs
 - Accurate off-road emission inventories

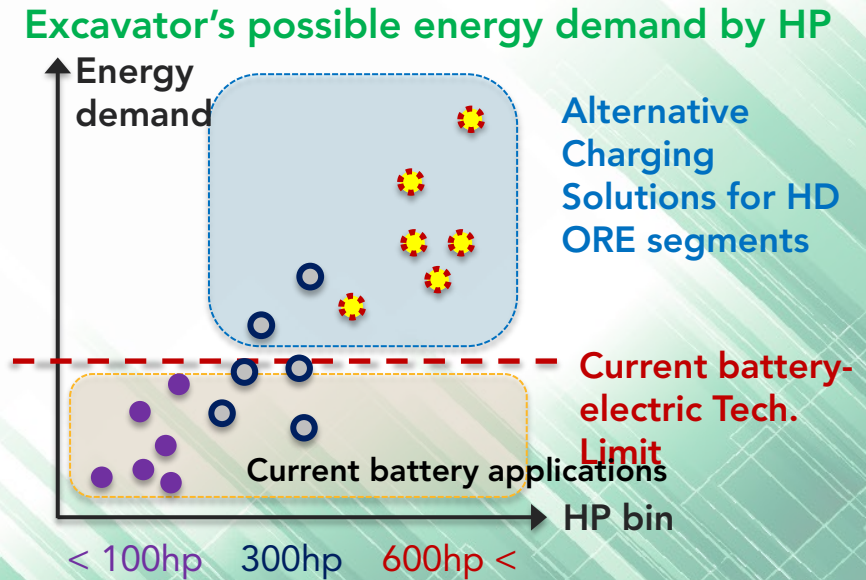
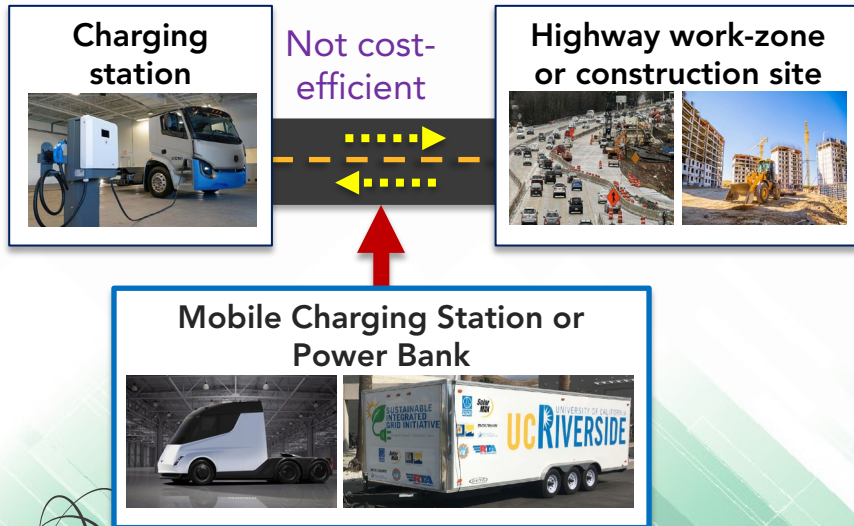
Potential ZE Segments of CHE sector

- High ZE Potential segments defined by equipment type and horsepower bin based on existing commercial equipment



Alternative charging solutions for HD ORE

- Current battery-electric technology is limited to electrifying heavy-duty off-road equipment (HD ORE) due to weight, charging time, total power, and availability of infrastructure
- Alternative Charging solutions are a critical key to the HD ORE electrification



Alternative Power & Charging Options

Plug-in Battery Electric



Grid-electric



Mobile Power Station



Battery Swapping System



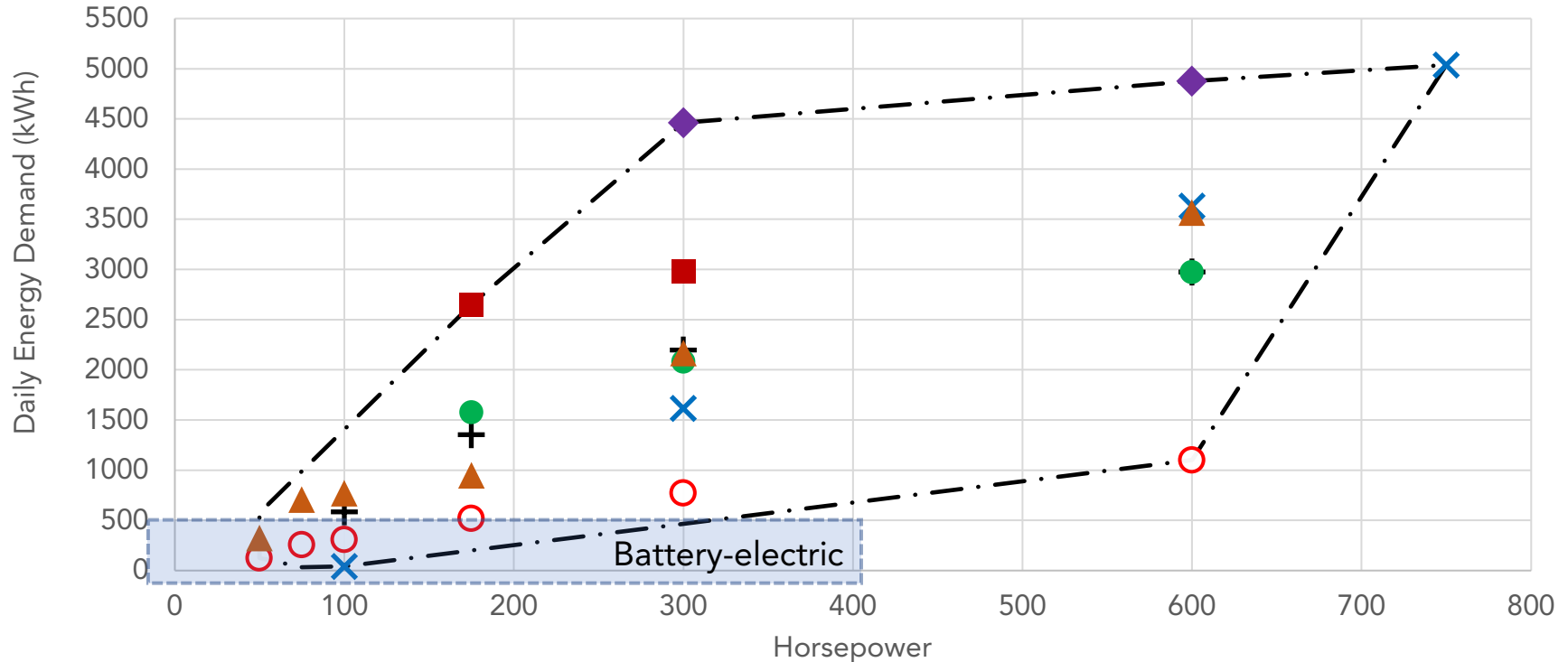
Catenary (trolley) System



Hydrogen Fuel Cell Powered



Combined Charging Strategy to Cover Varied Applications



— · Cargo Handling Equipment

○ Port Forklift

▲ Port Construction Equipment

+ Port CHE

● Port Yard Tractor

◆ Rail RTG Crane

× Port RTG Crane

■ Rail Yard Tractor

Impact of Alternative Charging Solutions

- Alternative charging solutions will expand the portion of the equipment population that can be converted to ZE, and greatly increase the potential emission benefits
- With the 100% market penetration assumption, the current ZE technologies cover the following portions of the total population and emissions.

Off-Road Equipment with Potential for ZE Conversion

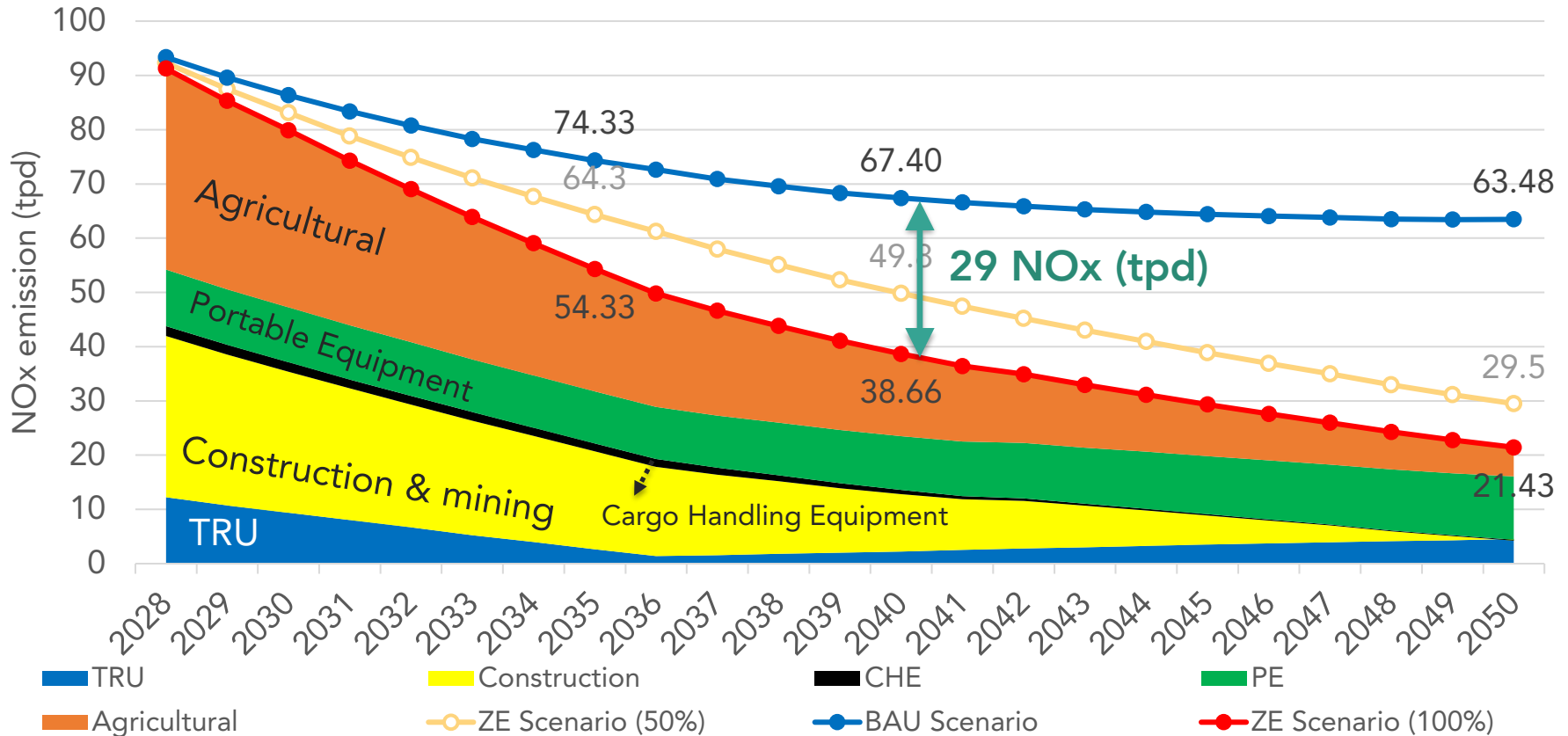
	By Population	By NOx Emissions
Current Commercial Applications (primarily battery electric)	71%	30%
Using Combination of Alternative Charging Strategies	96%	76%



Potential for Significant Emission Benefits

- Electrifying off-road equipment could provide significant emission benefits
- Modeling based on the latest CARB off-road inventories and the investigated demo and commercial ZE models in the world
- Assumptions
 - Uniform daily energy demand
 - ZE sales start with high ZE potential segments in 2028 and diffuse to all off-road sales by 2040 using alternative charging solutions
 - 50% & 100% of new adoptions are ZE, as bounding cases
 - Considers currently adopted rules (no Tier 5 standard)

Estimated NOx Reduction



Conclusions

- ORE manufacturers expanding zero-emission model offerings
- Understanding and analyzing in-use activity is key to determining the feasibility of ZE equipment
- No one silver bullet for full electrification in ORE sectors, but a combined strategy can cover various end uses
- Next steps include ZE technology's equipment purchase and operation cost factors

Acknowledgment

The solutions and suggestions presented in the study represent an analysis of the technology at the current moment; however, zero-emission options are constantly developing, improving, and working for a wider set of applications. This result does not indicate the approaches, concepts, or limitations of future regulatory actions of CARB.

Questions, Comments, Feedback

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