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

2023 CRC Workshop
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CARB

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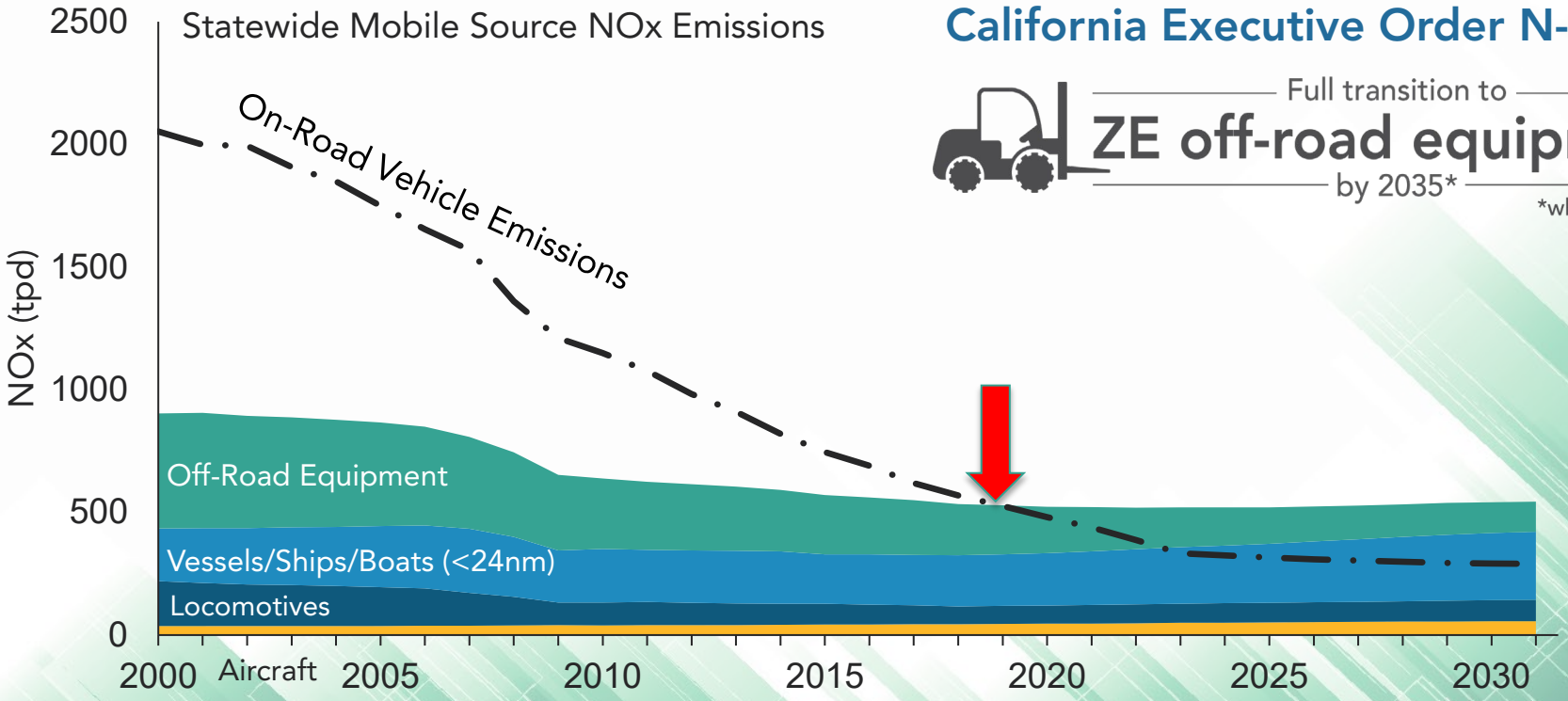
Zero-Emission Off-Road Equipment

Growing Importance of Off-Road



California Executive Order N-79-20

Full transition to

ZE off-road equipment

by 2035*

*where feasible

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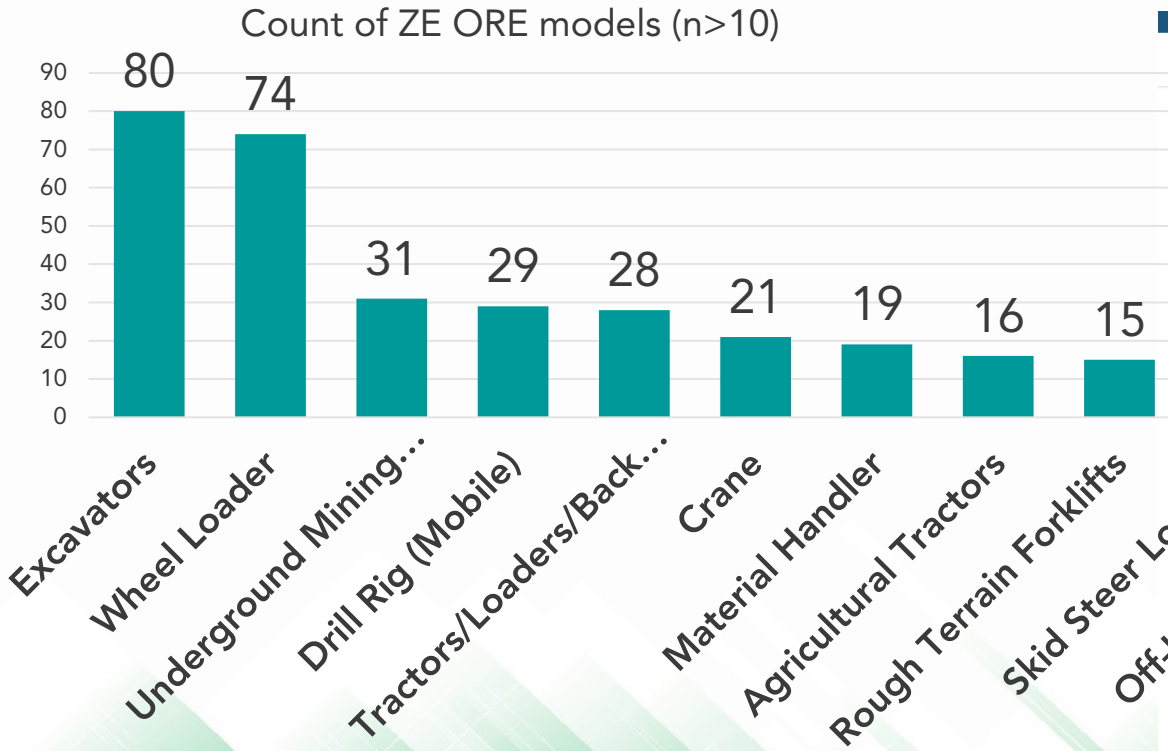
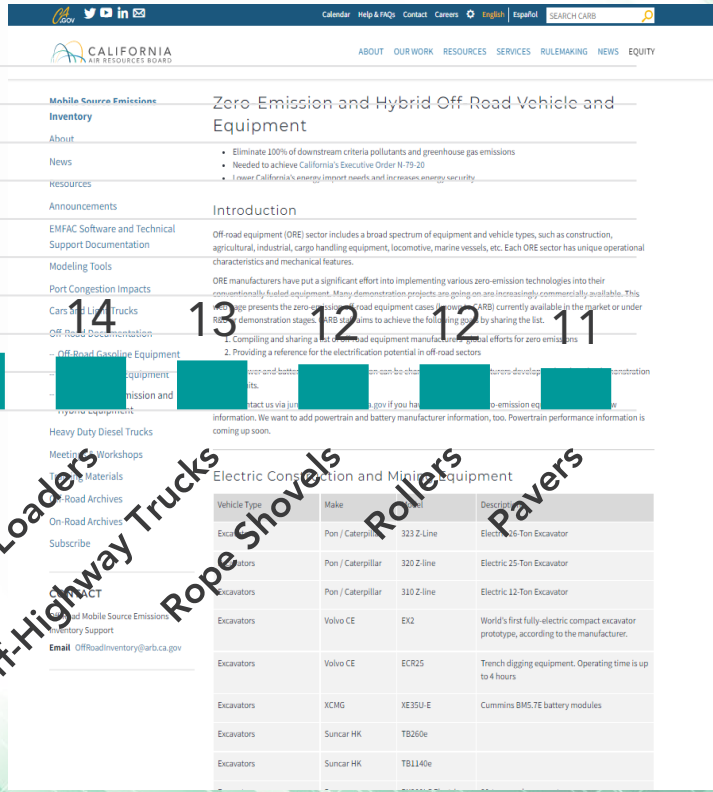
Ref: CEPAM 2019 Summer

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

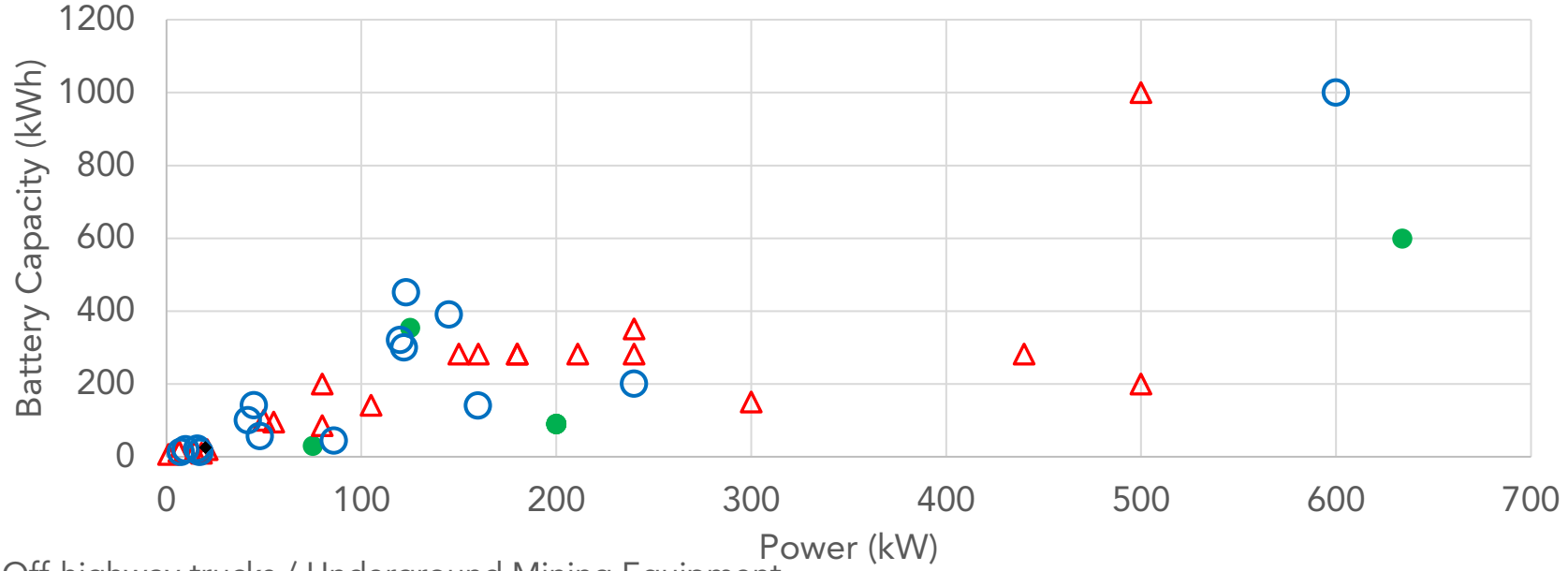




- This is based on a limited market research and includes commercial and demo battery-electric, H2FC, & grid-connected models
- 50 ORE types with 64 models were excluded from the ZEE list (https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/road-documentation/msei-documentation-road-1)

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

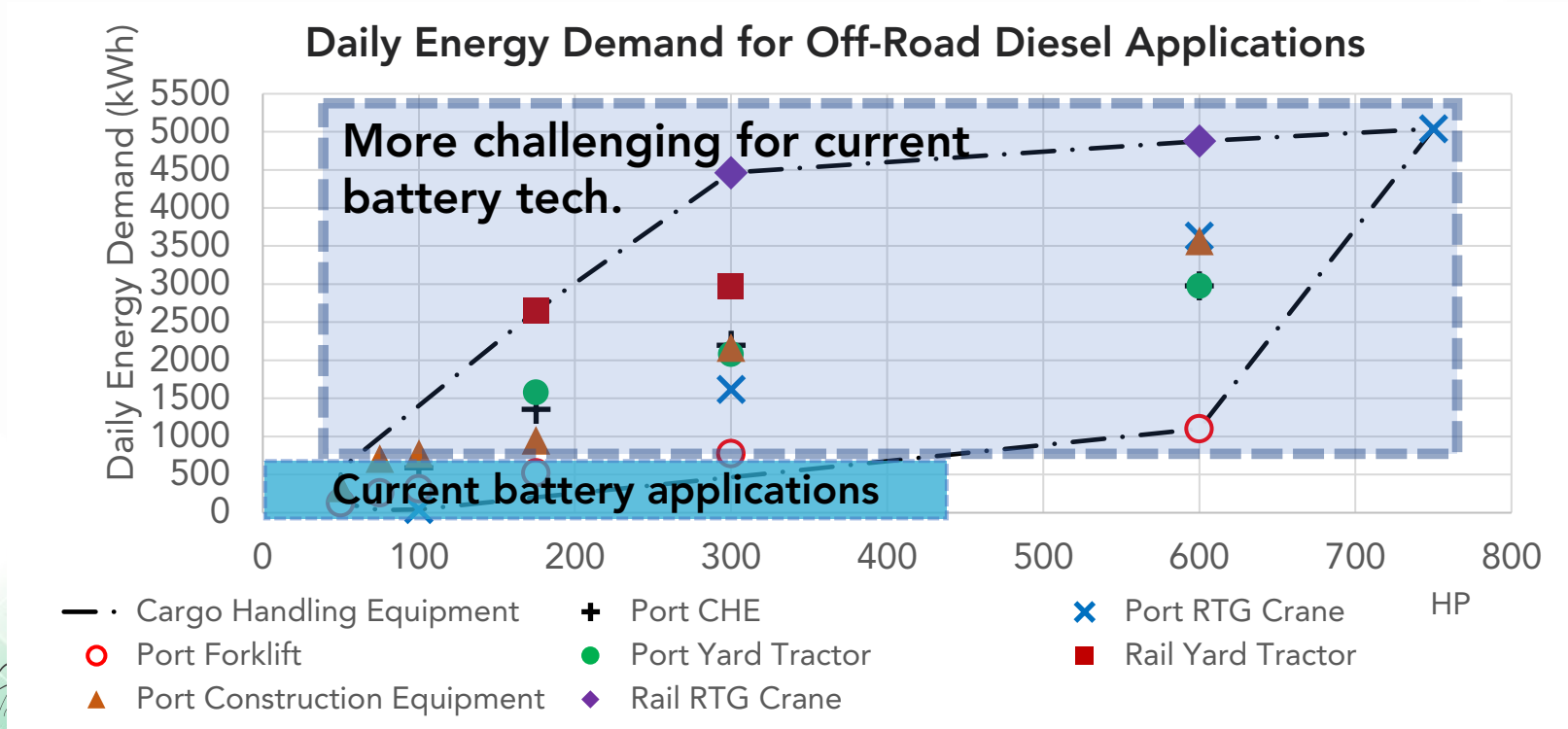


Forecasting ZE Adoption

- 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

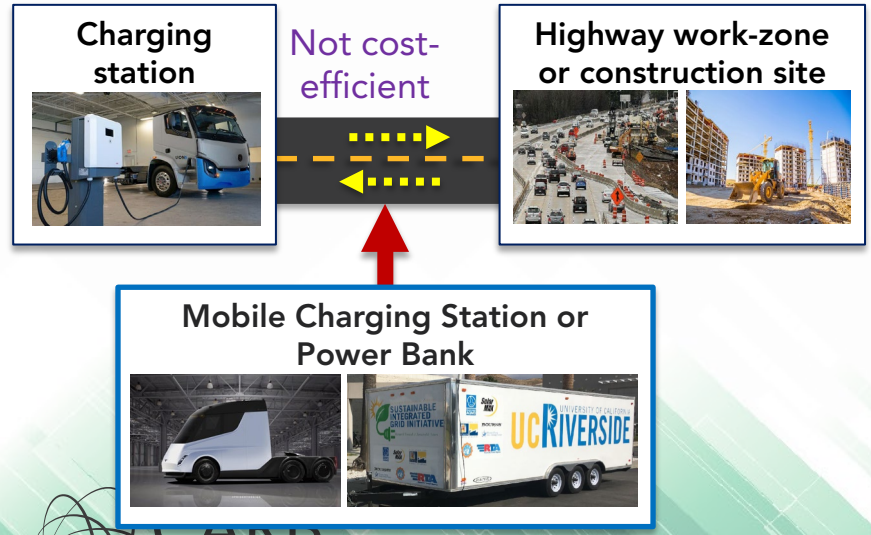
Potential ZE Segments of CHE sector

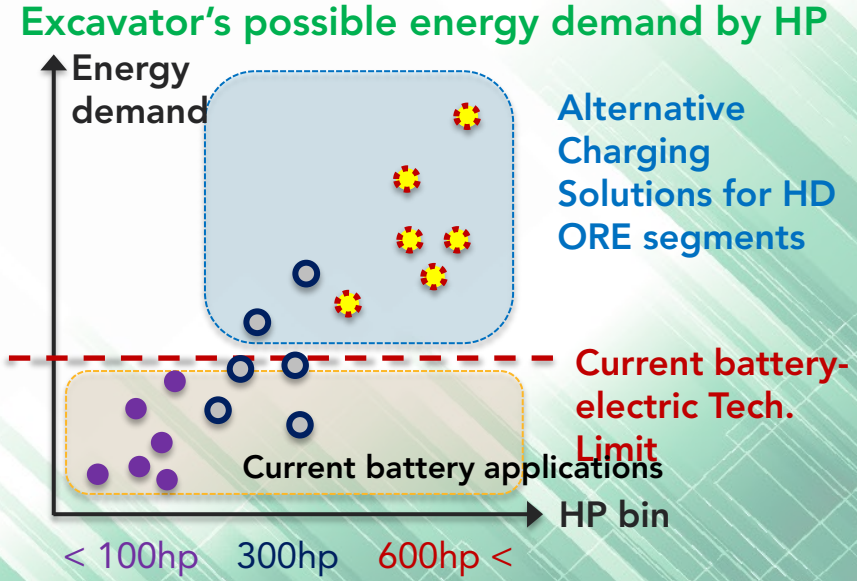
- High ZE Potential segments defined by equipment type and horsepower bin based on existing commercial equipment



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

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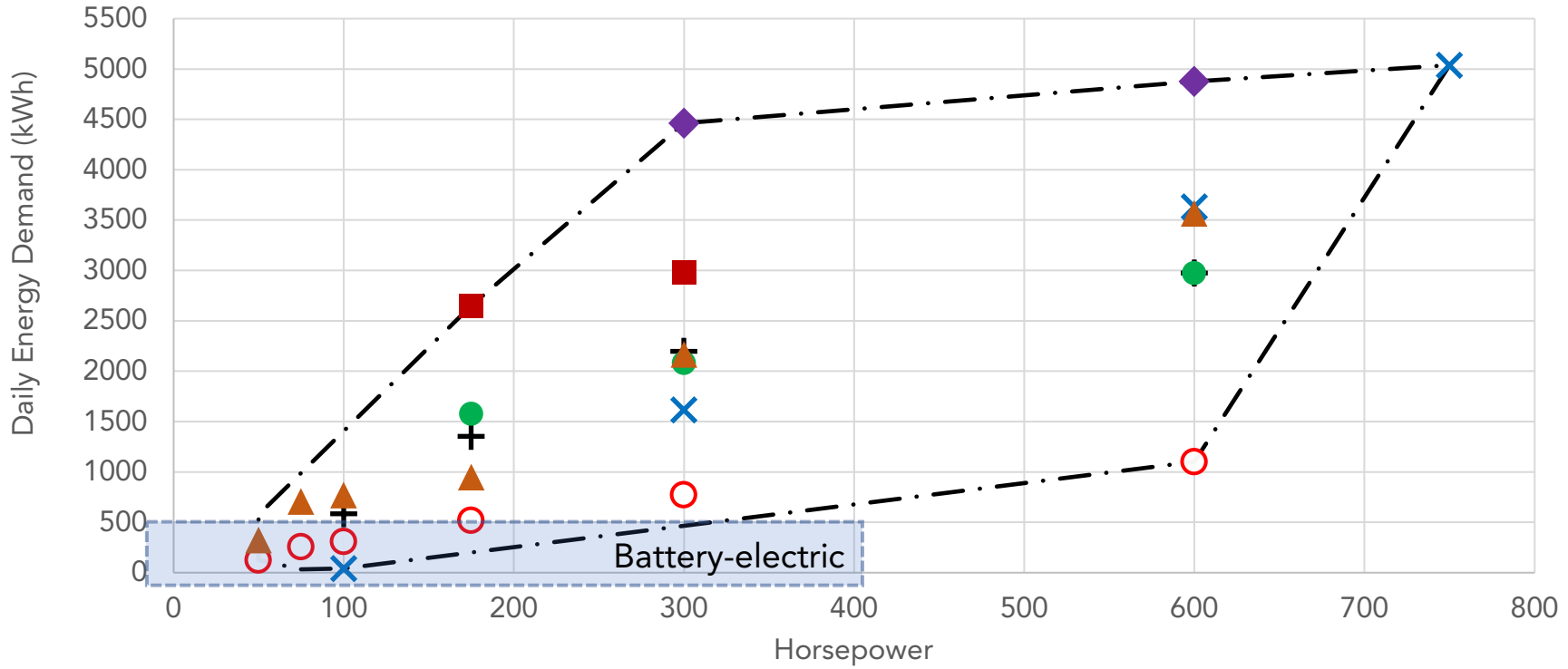
Combined Charging Strategy to Cover Varied Applications



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.

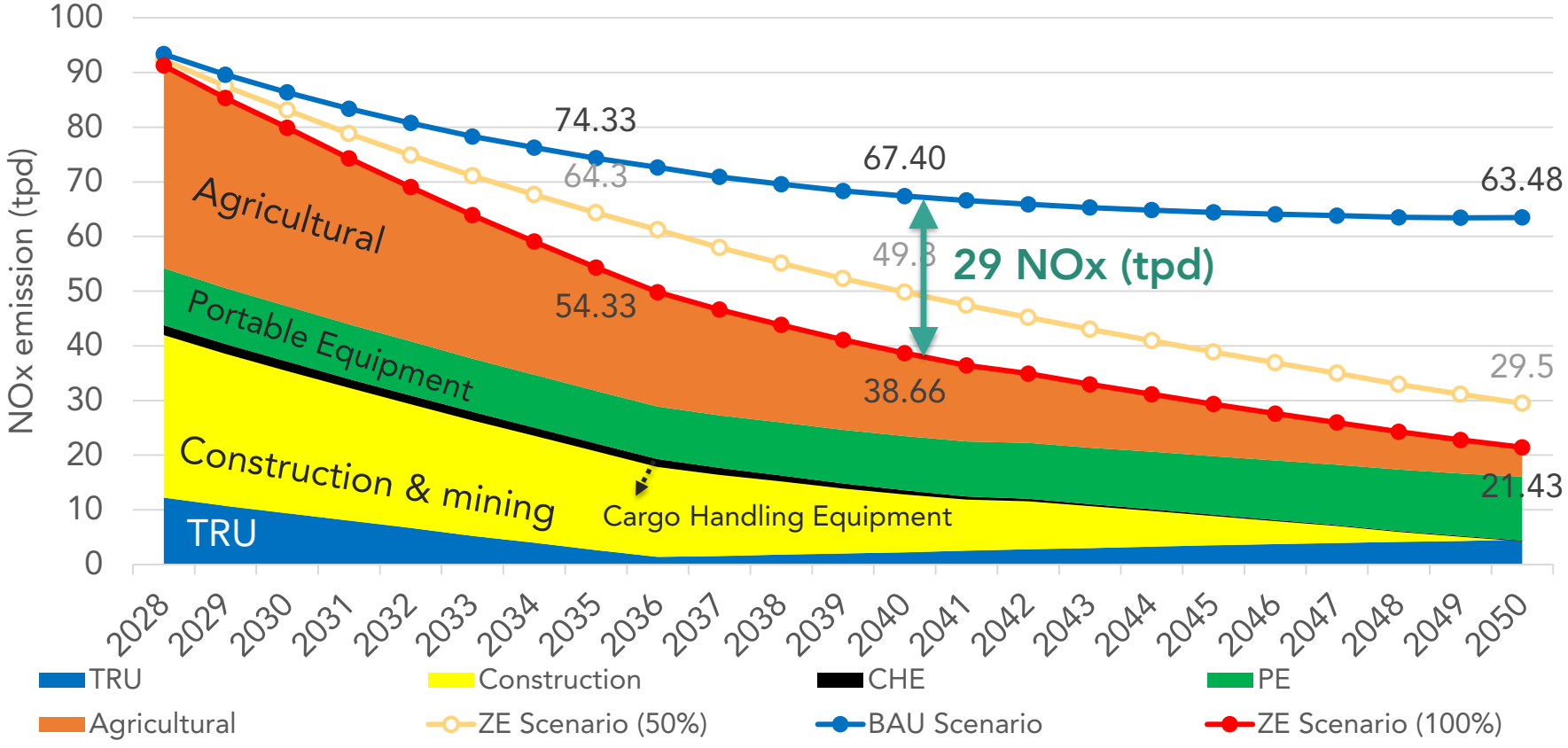
Off-Road Equipment with Potential for ZE Conversion

	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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