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Decarbonizing Heavy-Duty Vehicles in the U.S.

Arthur Yip, PhD

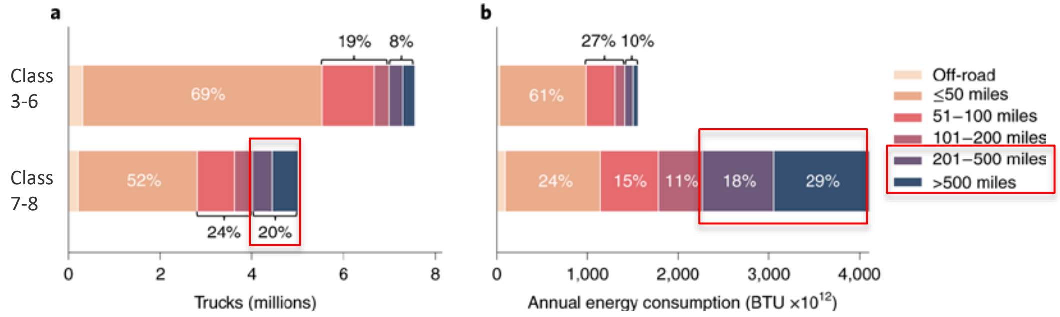
Based on research by Catherine Ledna, Matteo Muratori, Arthur Yip, Paige Jadun, Chris Hoehne, Brennan Borlaug, Jesse Bennett, and others at NREL

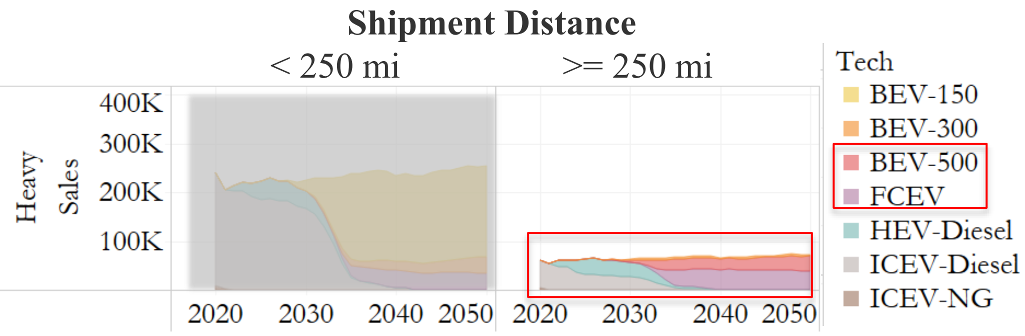
HEC Workshop on Decarbonizing Long-Haul Trucking in Eastern Canada

April 2023

NREL 2022 Medium & Heavy Duty Zero Emission Vehicles Cost Analysis

TEMPO





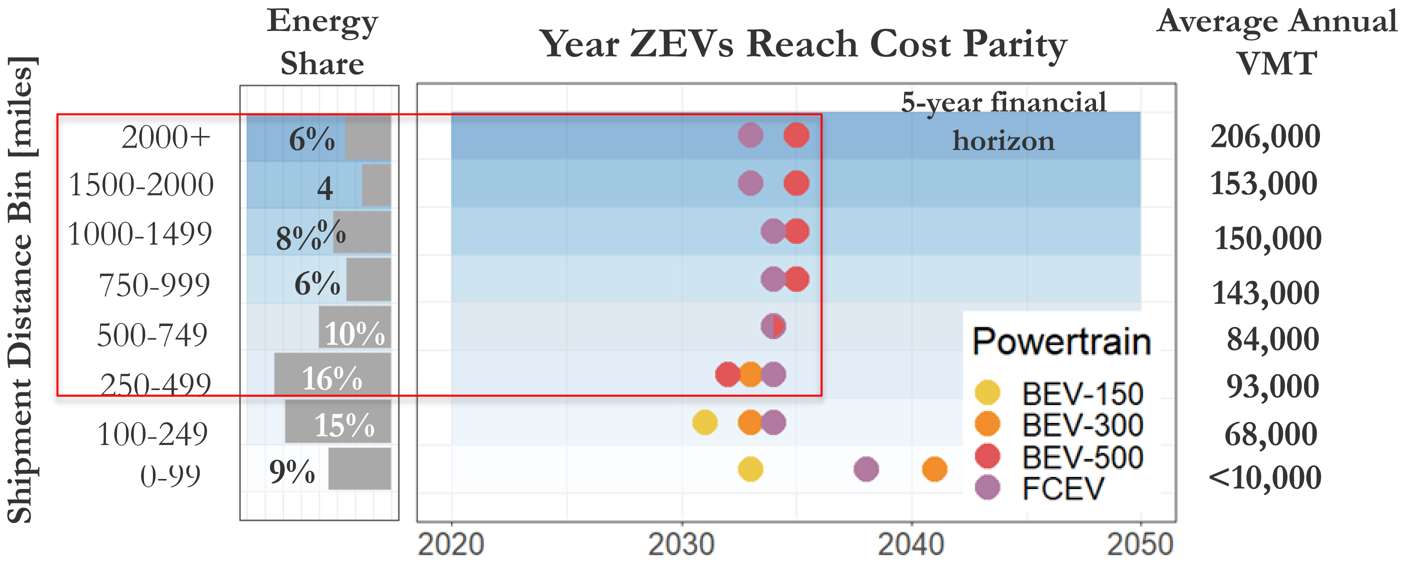
Class 8 Long-Haul Trucks in the U.S.

- Small in truck numbers
- But large in energy use and emissions
- Relatively difficult to decarbonize

Projected "cost parity" for ZEVs in the Class 8 Long-Haul segment

- *Even without IRA subsidies*, both BEVs and FCVs are projected to become cheaper in total cost than ICEVs by 2035
- This is expected to result in economic-driven adoption/demand/sales (but possibly limited by infrastructure)
- Balance between BEVs and FCVs sensitive to assumed fuel prices and infrastructure

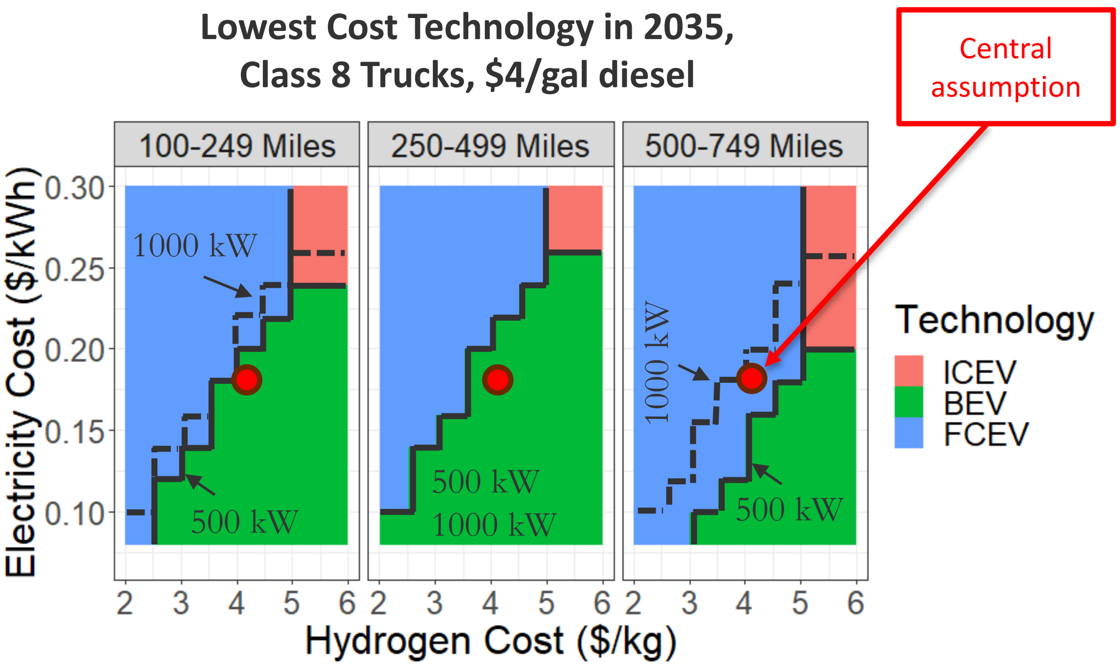
Projected Timing of Cost Parity of Class 8 Trucks by Distance Bin



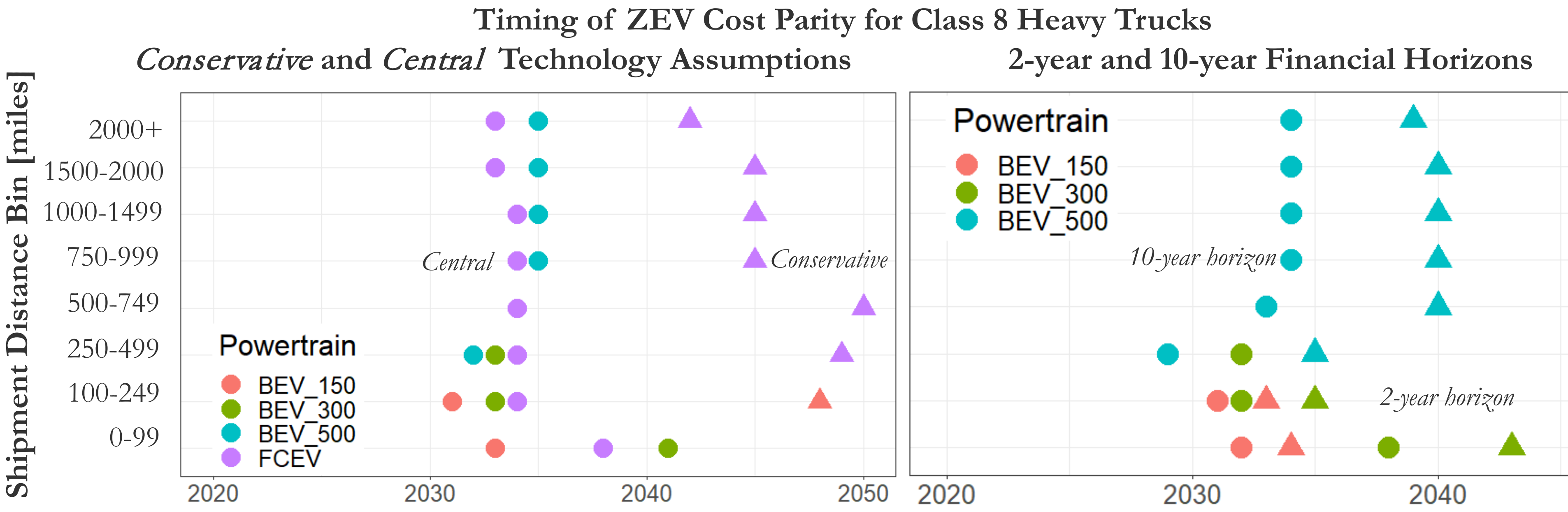
- **Either BEVs or FCVs are projected to achieve cost parity** (fuel and maintenance savings sufficiently paying off capital costs) **with ICEVs by 2035** in every distance bin
- Multiple technological solutions can provide necessary options and optimal choices for various applications
- BEVs have advantages in shorter-distance bins
- Analysis here assumes full fueling/infrastructure availability for both BEVs and FCVs

Impact of Fuel Prices on Projected Least-Cost Powertrain in 2035

- The least-cost technology is highly sensitive to fuel prices, which are uncertain and dependent on many factors.
- In addition, BEV charging speed will vary and affect convenience, viability, and potentially, cost.
- **Central assumptions in this study are close to separation line,** indicating multiple pathways for decarbonization.



Assumed Technology Forecast and Financial Horizon also affect Projected Timing of Cost Parity

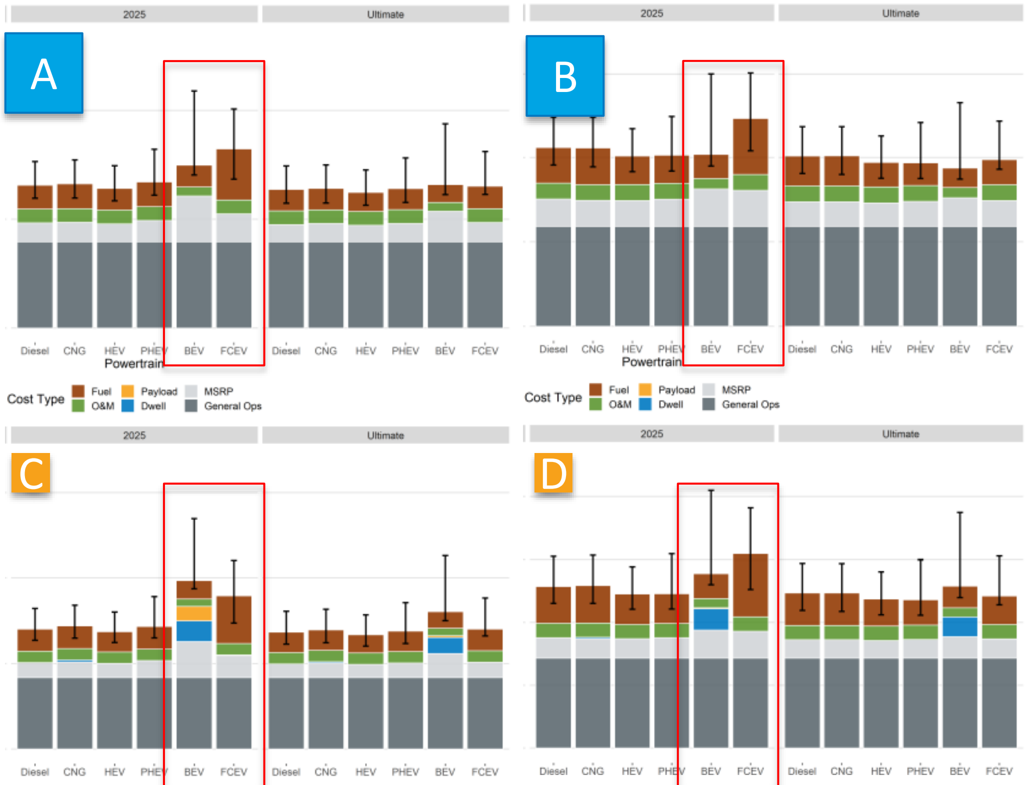


- Other assumptions also affect results and were assessed for impact on results
- US DOE projections and goals for vehicle costs and performance available for others to evaluate and use

Cost competition between ZEV varies by application and scenario

Single-shift, volume-limited

Multi-shift, weight-limited



Long-haul / Sleeper (750-mi)

Short-haul / Daycab (300-mi)

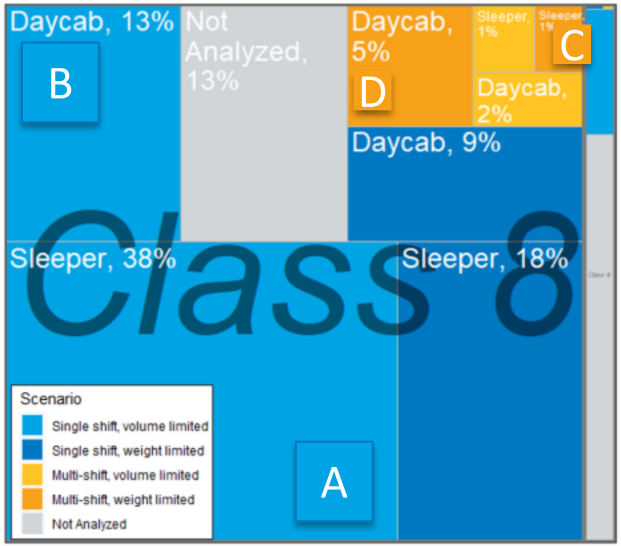
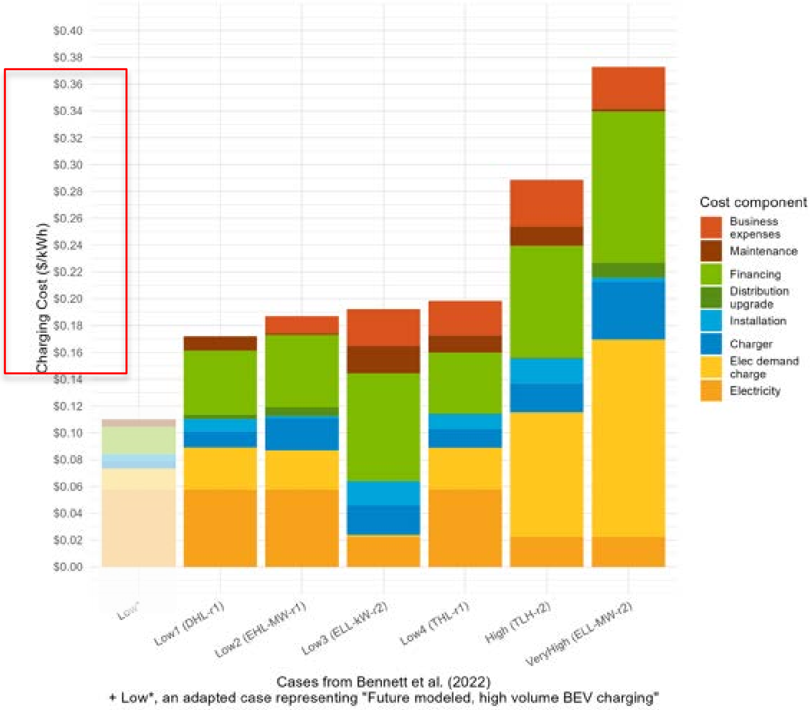


Figure 12. Estimation of percentage of Class 8 and Class 4 trucks associated with each scenario considered in this study based on VIUS data updated with Department of Motor Vehicle registration data (Lustbader et al. 2021; U.S. Census Bureau 2002; R.L. Polk and Co. 2013)

TCO ($/mile) for Class 8 tractors in different applications and scenarios (Hunter et al. 2021)

The cost of HD BEV charging (& H2) is uncertain, dependent on application and utilization

- Analyses have typically centered around vehicles, with fuel prices as an input factor
- More analysis is needed on infrastructure costs, how these can be distributed, and the variety of prices at which different types and models of charging can be offered
- NREL study "Estimating the break-even cost of Class 8 BEV charging stations" (Bennett et al. (2022)) assessed costs of various cases (application, power level, scenario)
- Critical factors and assumptions include:
    - **Electric rate demand charges**
    - **Electric grid distribution upgrades**
    - **Utilization, chargers per truck, chargers per distance (corridor coverage), fleet size**
    - **Queuing/charging management**
    - **Electric power and rate access at existing facilities**

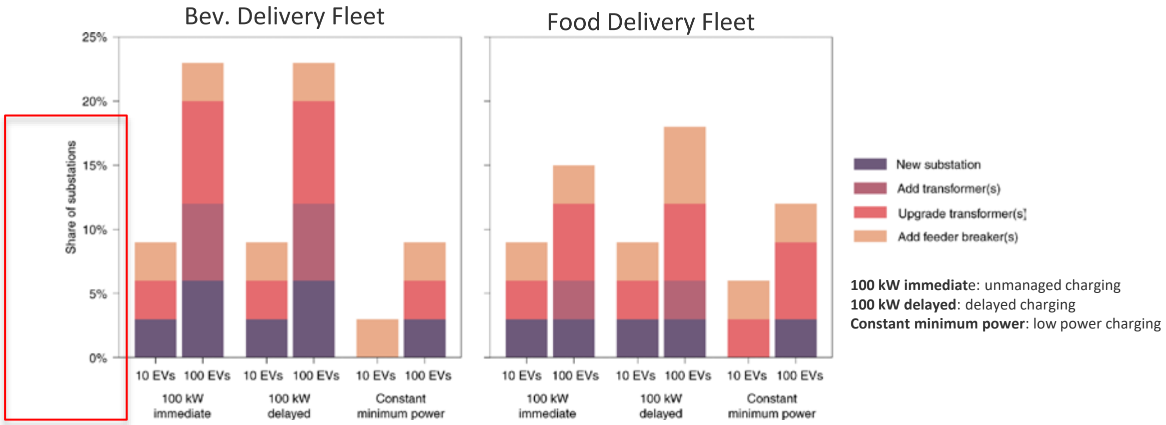


Similarly, although hydrogen prices have the potential to be low, particularly with IRA subsidy ($0.75-3/kg),

- Forecasts typically rely on embedded assumptions about future cost reductions, scale, learning, access to cheap electricity/CCS, high-volume/highly-utilized delivery and dispensing

Class 8 regional-haul tractor BEVs could charge at depots overnight, with relatively low impact on local power grid and minimal dependency on public EVSE

- Analysis of truck fleets show long dwell times enabling **depot charging at DCFC power levels in line with current light-duty EVSE (<150 kW)**.
- Each **additional EV contributes ~10-74 kW peak load** to the system, depending on fleet's operating schedule and charge management strategy

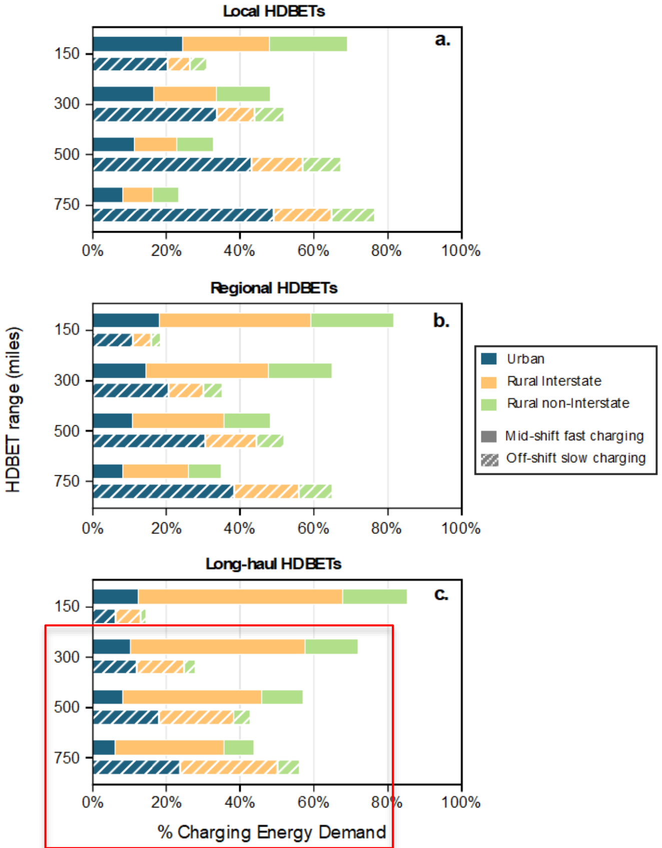


Share of real-world Oncor (TX) substations requiring specific capacity expansion upgrades to accommodate electric trucks charged at their depots.

[7] https://doi.org/10.1038/s41560-021-00855-0

Off-shift charging can meet substantial charging needs for Class 8 tractor BEVs, including for long-haul

- Based on analysis of large-scale vehicle telematics data, **off-shift charging at <350 kW can supply a significant share of total energy demand** in all operating segments, including long-haul, especially as battery range is increased.
- **Mid-shift charging will require MW-level charging,** especially in time-sensitive long-haul applications.



[8] Preprint: https://dx.doi.org/10.2139/ssrn.4079508

Despite uncertainty, the U.S. is moving ahead with substantial funding & ambitious targets for MHD ZEVs

Inflation Reduction Act (provisions in effect until 2032)

- Commercial Clean Vehicles: **$40,000** (no domestic requirements)
- Advanced Manufacturing Production: **$45/kWh** for domestic batteries
- Advanced Energy Investment: **30%** for EV or FC manufacturing
- Alternative Fuel Refueling: **30%**
- Clean Hydrogen: $0.75-**3/kg**, on top of Clean Electricity or CCS credits
- Clean Electricity: **30% ITC** or **$0.03/kWh** PTC, with requirements and adders
- Additional $ (billions) in loan and grant authority

California Advanced Clean Truck regulations (also adopted by New York & other states)

- **40% ZEV tractor sales by 2035**

Proposed US federal EPA GHG regulations

- **25% ZEV tractor sales required by 2032**

Note that "tractor" is not necessarily long-haul; however, new tractors typically serve long-haul before moving into other less demanding applications

Recommendations for research: vehicles and market segmentation

- Foreseeable technological progress enables cost-competitive transition in the big picture and medium/long-term… but
- Detailed market segmentation should be performed for trucks/users of this specific corridor
- This matters greatly to whether shorter-range BEVs are suitable for the target market

Trucks exclusively traveling within this corridor	?	Trucks with trips beyond this corridor and range of expected fueling infrastructure e.g. deep into rural areas or deep into the U.S. (+ border delays?)
Trucks exclusively serving "short/local" or "line/regional-haul" fixed routes of known lengths and manageable within vehicle range	?	Trucks on "long-haul," with unpredictable distances, schedules, and dwell time
Large corporate fleets, more able to reconfigure schedules & logistics, substitute trucks, plan/invest in private infrastructure	?	Private owner-operators, less able to mitigate risk, may rely on public fueling infrastructure and used vehicle markets

Recommendations for research: fuel and infrastructure costs

- Detailed analysis is needed for the cost of fuel and infrastructure in various use cases and scenarios
- The economics and risk profile of self-owned/private charging/refueling can be very different from public fueling infrastructure investment and how it's paid for
- The economics of electricity (distribution upgrades, demand charges, utility rates) may change substantially, in parallel with decarbonization efforts
- Transparency in hydrogen costs/projections and more evidence from actual achieved and real-world utilization cases needed

Recommendations for research: infrastructure roll-out

- Network/corridor infrastructure build-out will inevitably be in stages
- Note that light and medium duty vehicles and short-haul tractors will likely transition/decarbonize earlier/faster, and likely via BEVs/electrification.
  - This can mean significant advantages for the BEV pathway

- Certain technologies and pathways can be deployed in a more scalable, distributed, risk-mitigated/capital-friendly manner e.g., BEV charging at private depots with partial/back-up coverage from public stations
  - Others (e.g., H2, catenary) rely on larger-scale networked/co-dependent investments in fuel supply and corridor infrastructure

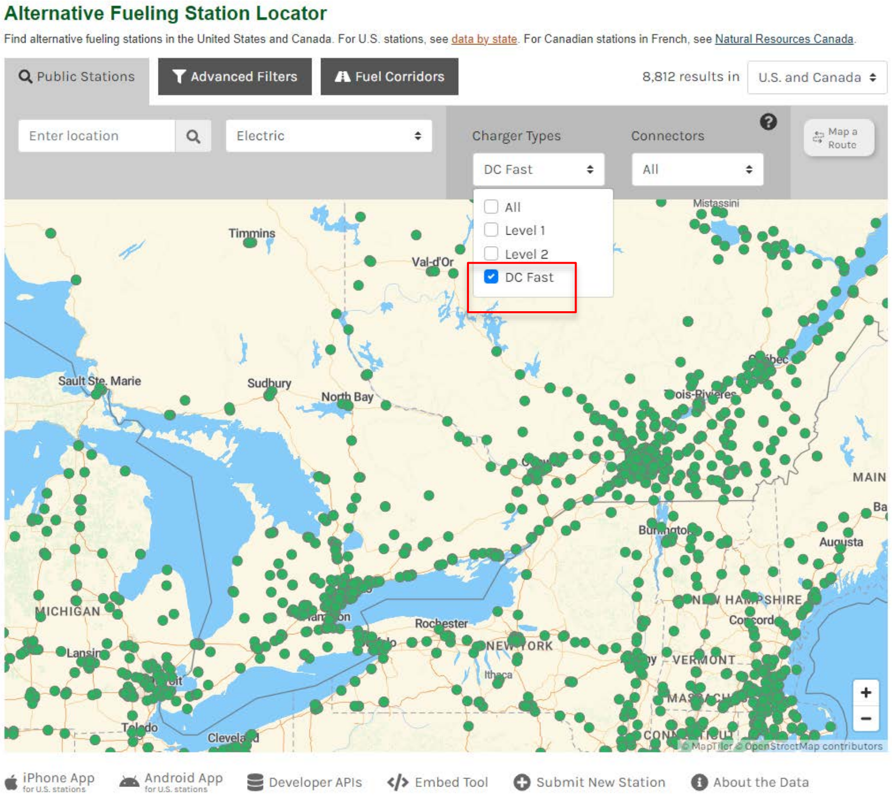
- Other intermediate options (alternative gaseous/liquid fuels, hybrid technologies) could be helpful in bridging gaps to full decarbonization (but are unlikely to be dominant)

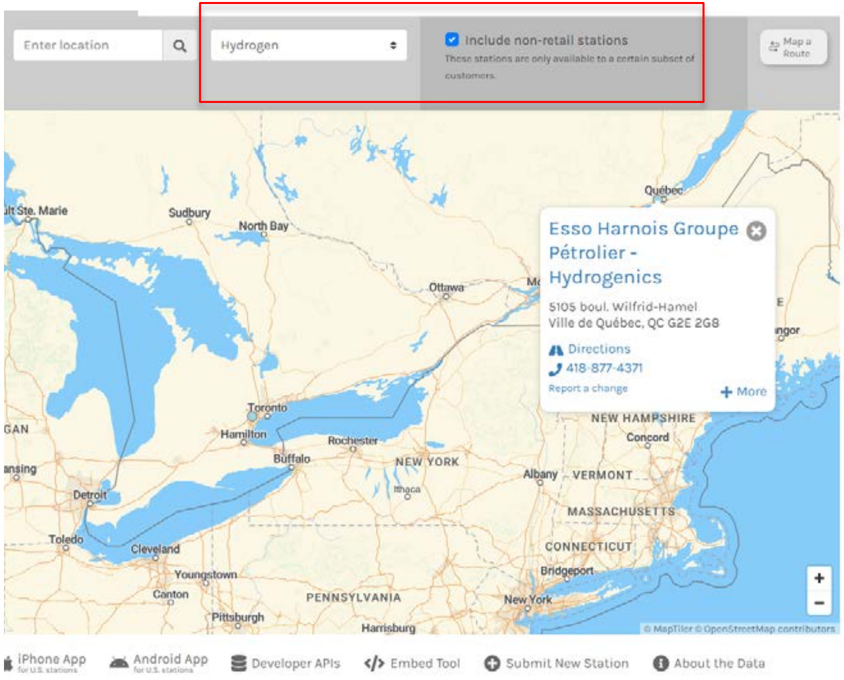
Recommendations for Canada-US collaboration

- Similarities in freight/trucking market structure mean that ZEV feasibility and adoption opportunities may be similar
  - Research should confirm and leverage this

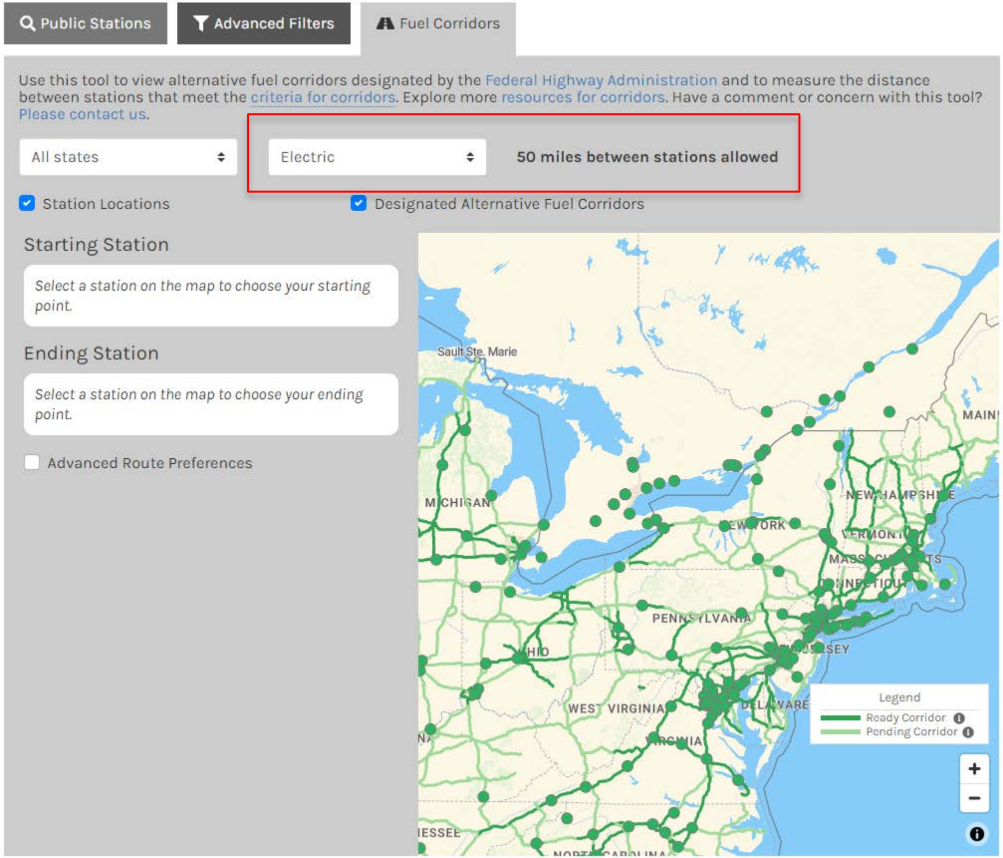
- NREL builds and maintains the Alternative Fuel Data Center (AFDC) for DOE and NRCan: cross-border light-duty vehicle traffic can already use an integrated Alternative Fueling Station Locator
  - Perform analysis with existing infrastructure and other near-term trends as important context

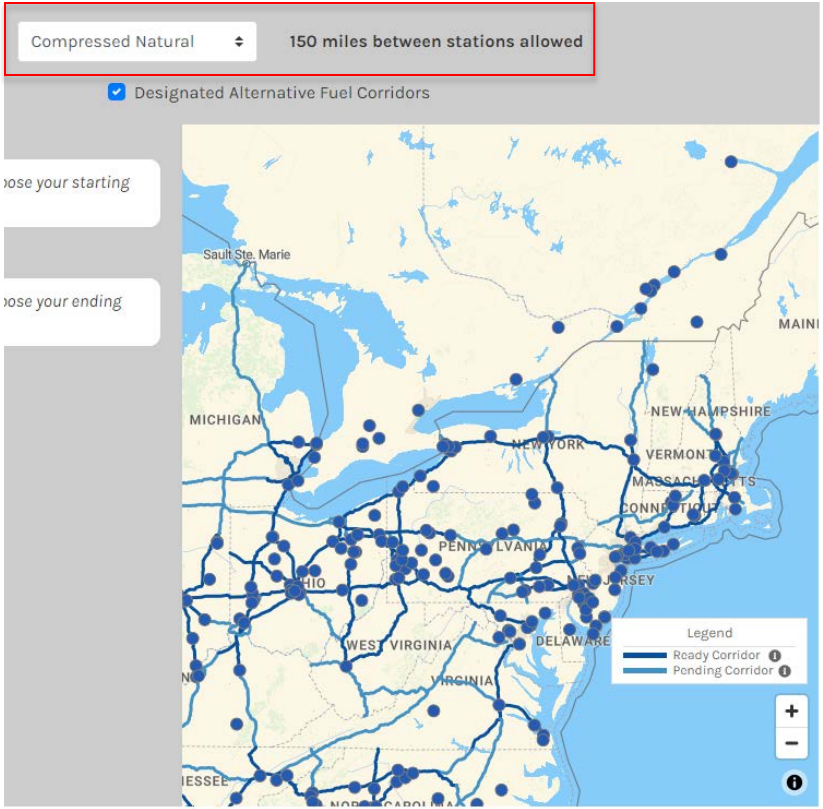
AFDC shows locations of existing alternative fuel infrastructure





AFDC also tracks US FHWA's designated Alternative Fuel Corridors





Arthur Yip
arthur.yip@nrel.gov

Thank You

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