Keeping It Real: Regional Haul, Zero-Emission, Heavy-Duty Tractors

August 6, 2020

ACT NEWS

RUN ON LESS REGIONAL

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

Keeping It Real: Regional Haul, Zero-Emission, Heavy-Duty Tractors

August 6, 2020

Moderated by Rick Mihelic

Director Emerging Technologies, NACFE

Before we get started:

Q&A

Submit your questions to the host using the Q&A box in the upper right-hand corner.

Presentations

A recording of today's webinar will be posted on the ACT News website and you will be emailed a link early next week.

Survey

A 30-second survey will pop-up at the end. We appreciate your feedback!

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Benjamin.Chan@gladstein.org
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Moderator:

Rick Mihelic

Director Emerging Technologies

North American Council for Freight Efficiency

The Real World

- Zero Emissions is the goal
- Battery Electric & Hydrogen Fuel Electric Trucks <u>are promising</u>
- They have to make sense in the real world
- The future is where predictions falter or excel

Freight Facts & Figures – North America

Trucks in Commercial Use

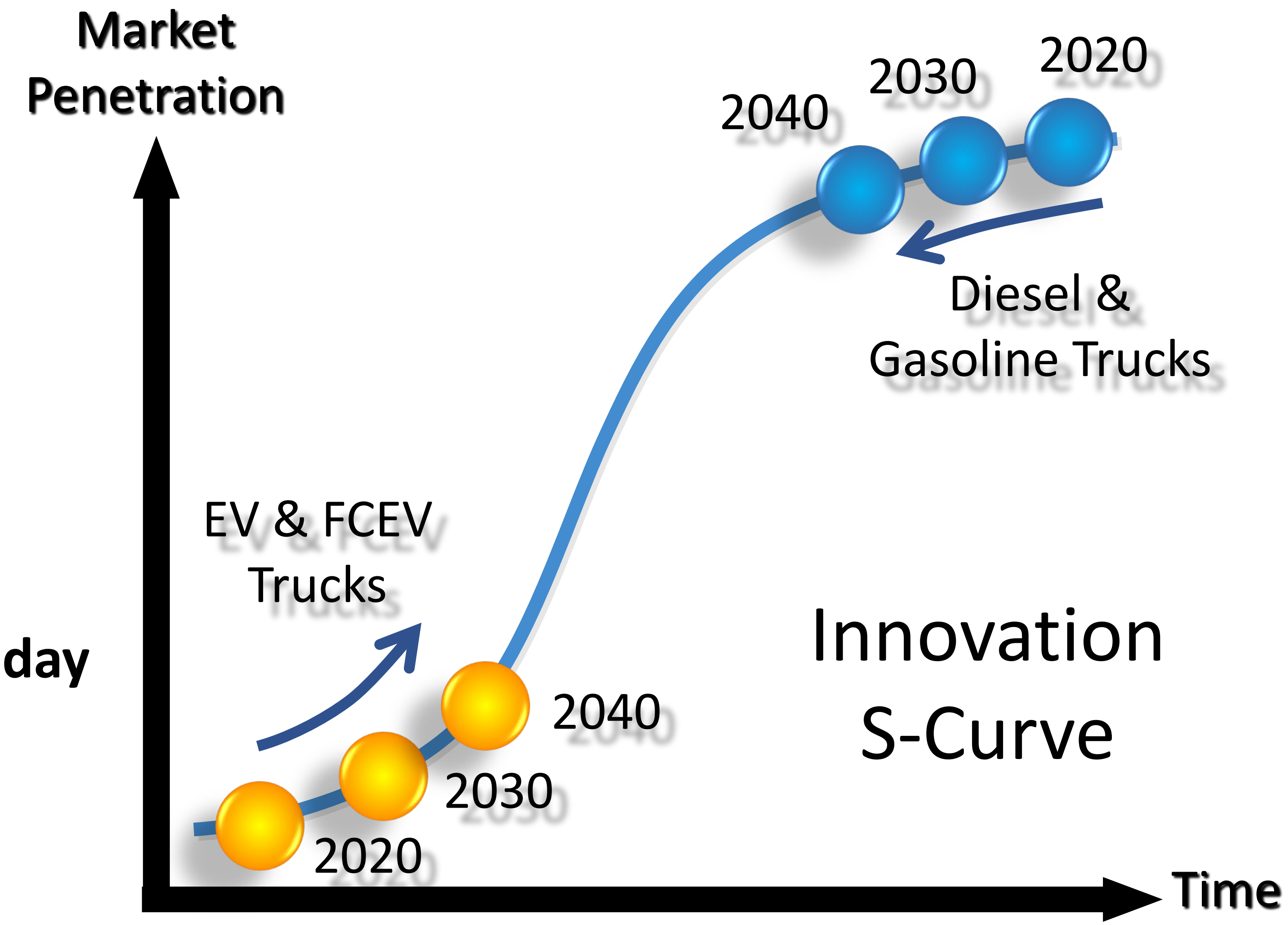
- 2.7M Tractors
- 8.8M Single Unit Trucks

Annual Production Capacity

- ~320k HD Truck/Tractors
- ~350k MD Trucks

Production EV/FCEV Trucks Today

- < 100 HD
- < 5,000 MD



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Today's Agenda

- NACFE collected 10 real world duty cycles for Regional Haul Class 8 Tractors in its Run on Less Regional event last October
- NREL and Ballard analyzed these for NACFE with respect to future
  - Battery Electric
  - Fuel Cell Electric
- Participants in this webinar will:
  - Hear the results from the Run on Less Regional event
  - Learn what is needed to adopt both battery-electric and hydrogen fuel cell technologies for regional haul applications
  - Understand the opportunities and challenges in transitioning from a diesel truck to a zero-emission vehicle

Today's Panelists

NACFE

Mike Roeth
Executive Director
North American Council for Freight Efficiency

NREL

Andrew Kotz, Ph.D.
Commercial Vehicle Research Engineer
National Renewable Energy Laboratory

BALLARD

Alan Mace
Market Manager
Ballard Power Systems

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Learnings from the Run on Less Regional

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Mike Roeth

Executive Director

North American Council for Freight Efficiency

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C&S WHOLESALE GROCERS
RUN ON LESS
REGIONAL
DRIVER
MARK CASEY
HIRSCHBACH
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GLEN WILLIAMS
HOGAN TRANSPORTATION
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SCHNEIDER
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BEAU SMITH
SOUTHEASTERN FREIGHT LINES
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REGIONAL
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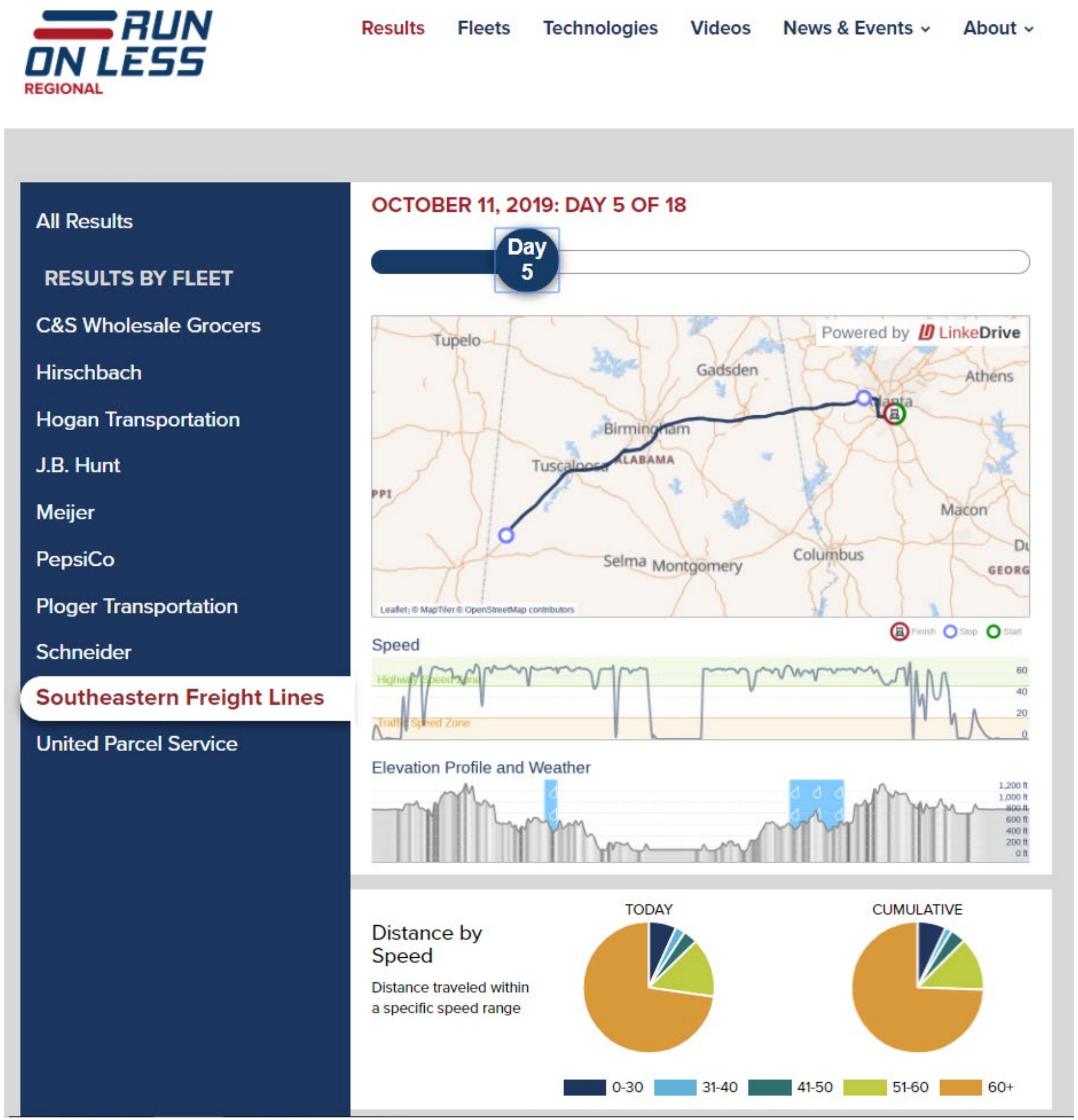
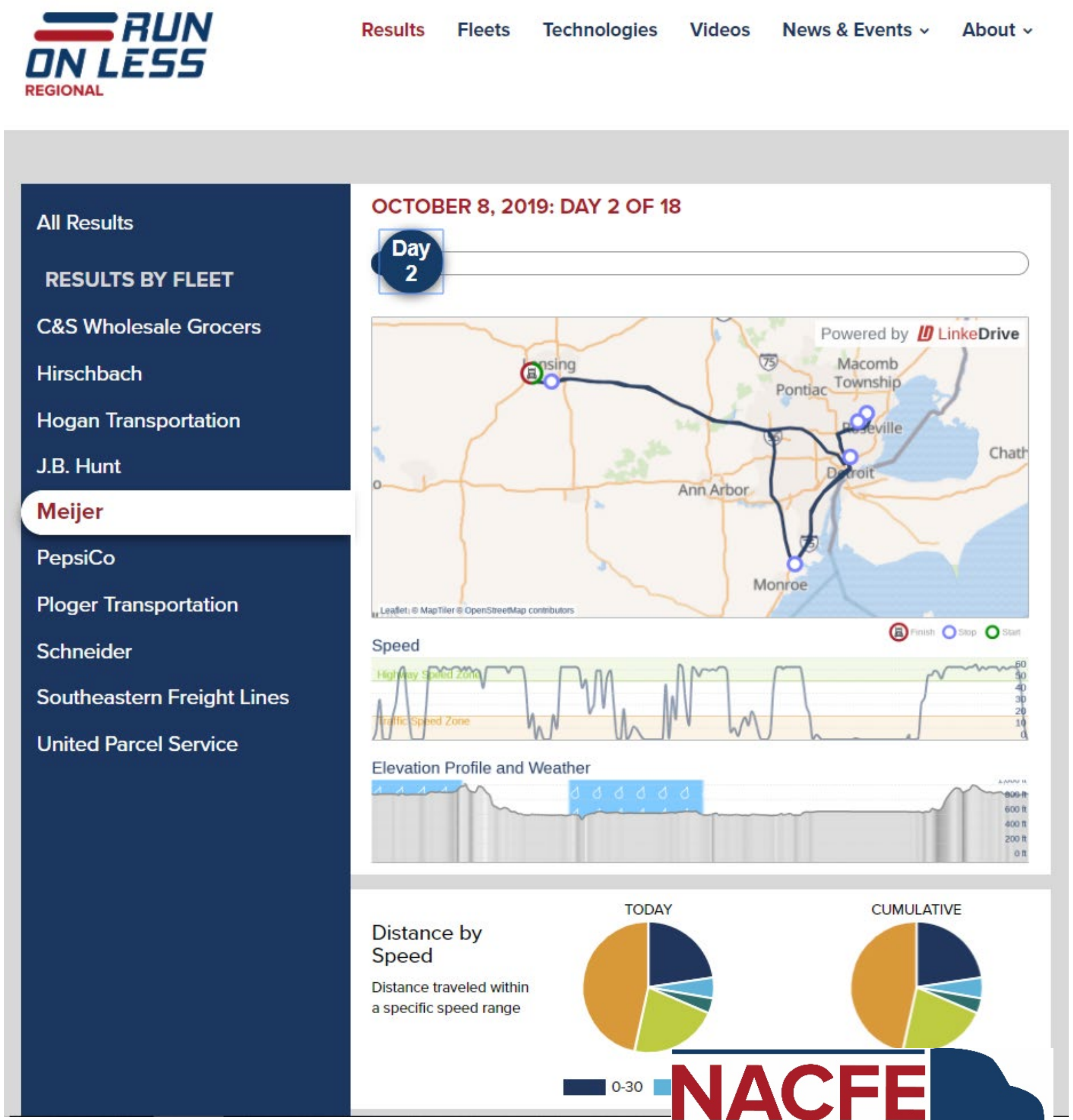
DARIN SALGADO
UNITED PARCEL SERVICE





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Technology Day Webinar Series

Webinar 1: October 8 - Hydrogen
Webinar 2: October 15 - Connectivity
Webinar 3: October 23 - Battery Electric

Presented in Partnership With ACT NEWS

WEBINAR 1 - October 8

Is Hydrogen a Viable Truck Fuel?

Time: 11 am PT | 2 pm ET

Sponsored by:

WEBINAR 2 - October 15

How Can Connectivity Improve Trucking Efficiency?

Time: 11 am PT | 2 pm ET

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PEPSICO

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Cummins

WEBINAR 3 - October 23

How Far Will Commercial Battery Electric Vehicles Go?

Time: 11 am PT | 2 pm ET

Sponsored by:

MERITOR RUN WITH THE BULL

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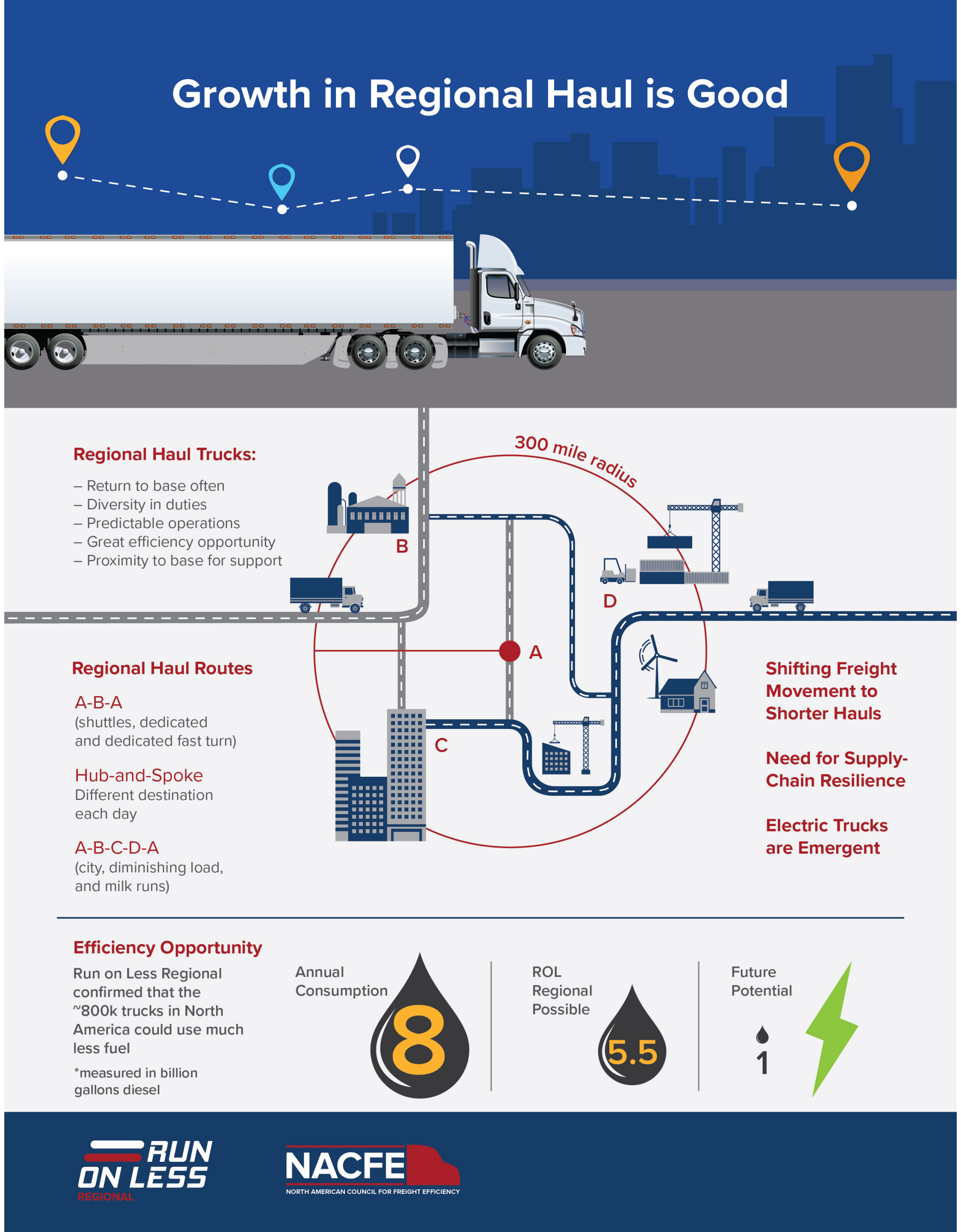

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Growth in Regional Haul is Good

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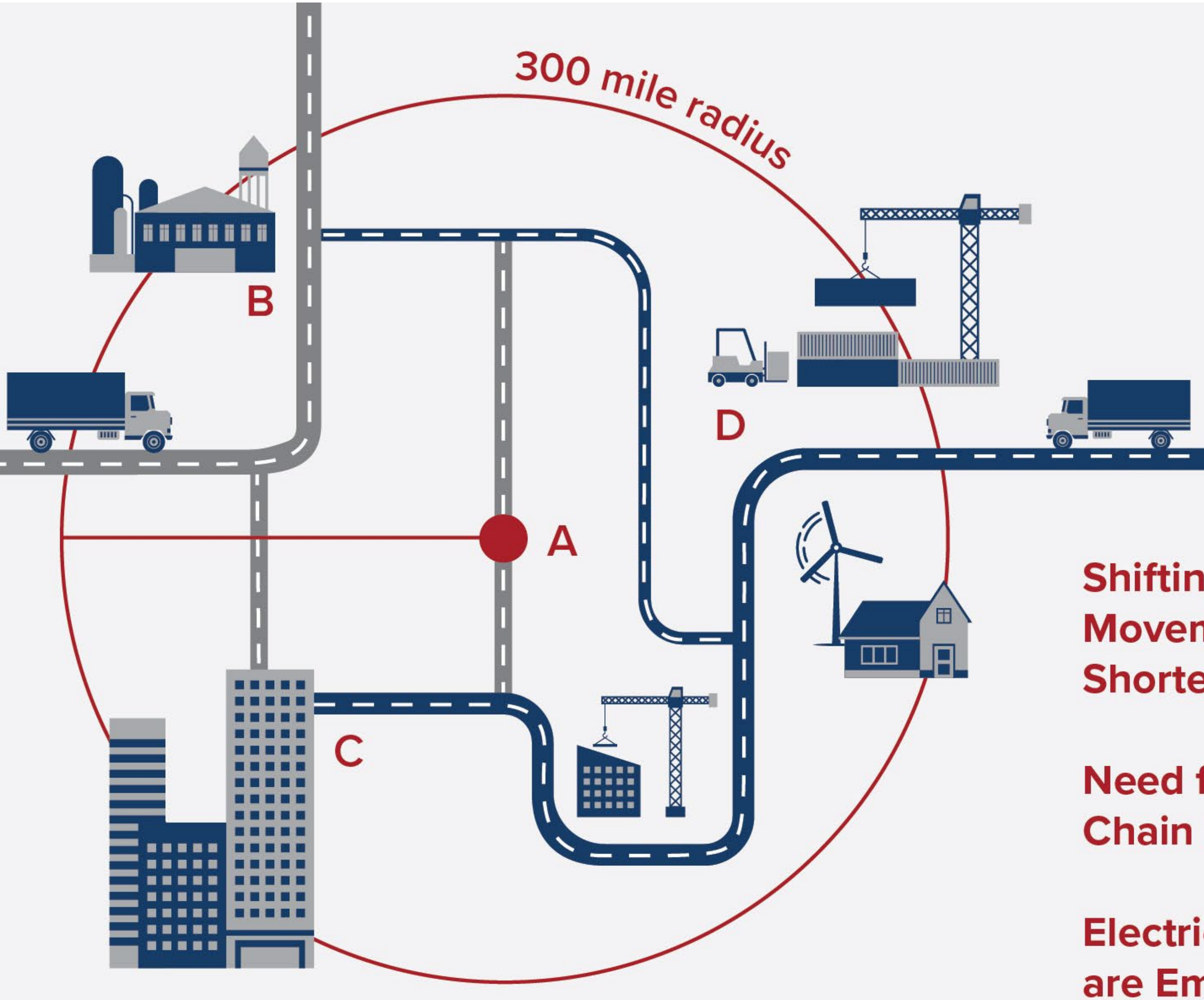
Regional Haul Trucks:

- Return to base often
- Diversity in duties
- Predictable operations
- Great efficiency opportunity
- Proximity to base for support



Regional Haul Routes

A-B-A
(shuttles, dedicated
and dedicated fast turn)

Hub-and-Spoke
Different destination
each day

A-B-C-D-A
(city, diminishing load,
and milk runs)

Shifting Freight Movement to Shorter Hauls

Need for Supply-Chain Resilience

Electric Trucks are Emergent

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REGIONAL HAUL DUTY CYCLE DEFINITIONS

RoLR Stated Duty Cycles		Duty Cycles	Definition	RoLR Fleets
A-B-A	"Out and back," same place every time	Shuttles	Short multiple runs <150 round trip	Hirschbach
		Dedicated	150 to ~400 miles RT	Hogan
		Dedicated Fast Turn	Full 1/2 day drive out ~500 miles RT	SEFL, UPS
Hub and Spoke	Different destination each day "out and back"	Hub and Spoke	A-B with different place each day	C&S, Schneider
A-B-C-D-A	Multiple stops during day	City	Multiple drops, low miles	None
		Diminishing Load	Drop offs only	JB Hunt
		Milk Run	Drops and pickups later in the run	Meijer, PepsiCo, Ploger

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Efficiency Opportunity

Run on Less Regional confirmed that the ~800k trucks in North America could use much less fuel

*measured in billion gallons diesel

Annual Consumption	ROL Regional Possible	Future Potential
8	5.5	1

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Hirschbach

Conclusions from NREL's work on electrifying the RoLR routes

NREL

Andrew Kotz, Ph.D.

Commercial Vehicle Research Engineer

National Renewable Energy Laboratory

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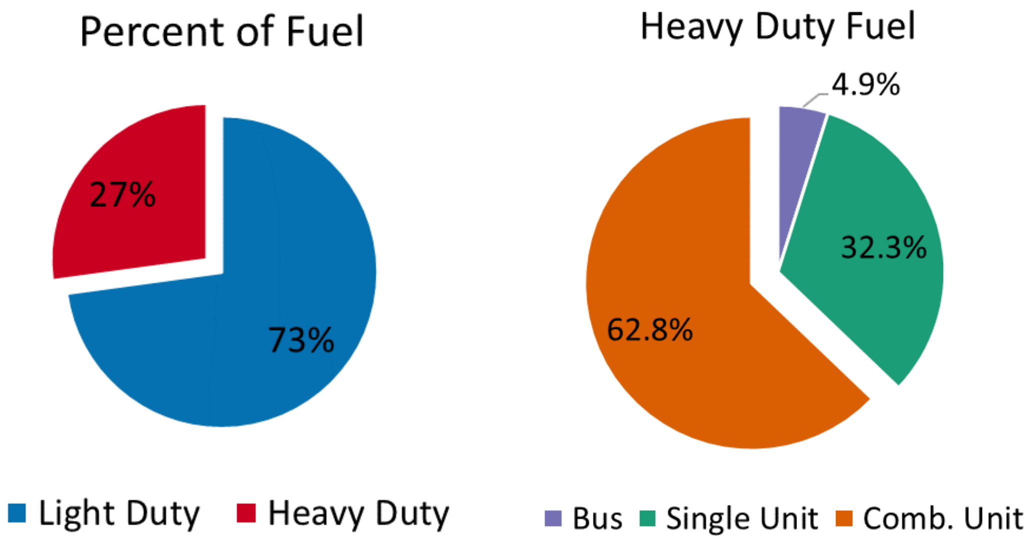
Regional Haul Electrification

Andrew Kotz, Ph.D.
Andrew.Kotz@nrel.gov

Motive for Electrification

Regional haul electrification

- Regional haul and long haul are two of the most challenging duty cycles
  - 1.1% of U.S. vehicles
  - 17% of fuel use
  - Avg. 62k miles annually
- Impact per vehicle
  - @ 6 MPG = 10,450 gal/year
  - 205,000 $lbsCO_2$/year
- Fleet
  - 298million $tonsCO_2$/year



https://www.fhwa.dot.gov/policyinformation/statistics/2017/vm1.cfm

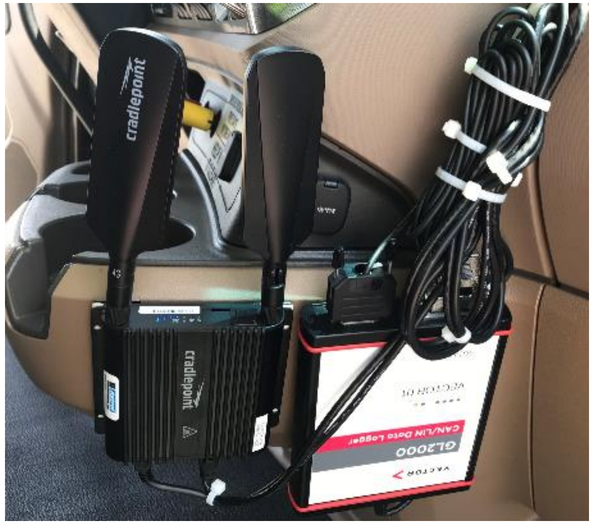
What would it take to electrify?

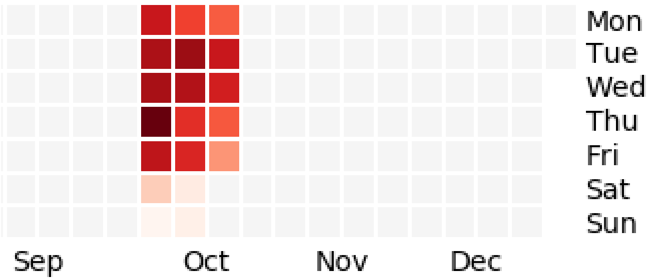
- **Battery Size**
- **Charge Rate**
- **Infrastructure**

ROLR Overview Stats

- NREL data collection - 2019
  - October 7th to 23rd
  - 10 Vehicles
  - Between 1Hz & 10Hz
- Geotab data collection: asynchronous
- Average combined daily distance: 3,417 mi (341 mi/day)
- Max combined daily distance: 4,920 mi (492 mi/day) – 10/10/19

Parameter	Miles of Data	Gallons Used	Hours of Operation	Vehicle Days
Value	58,090	6,434	1,921	142





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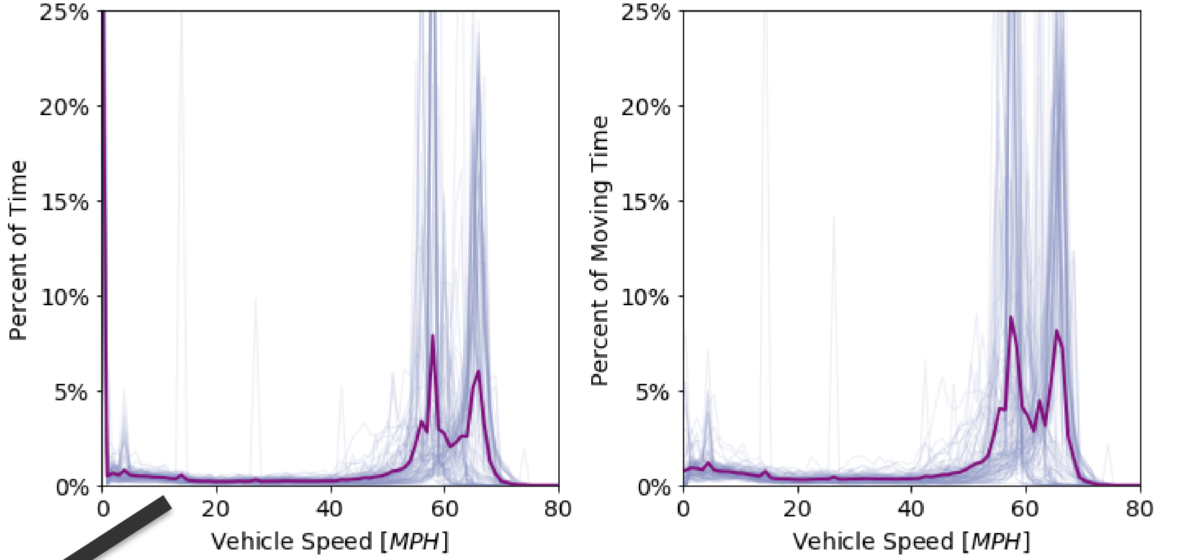
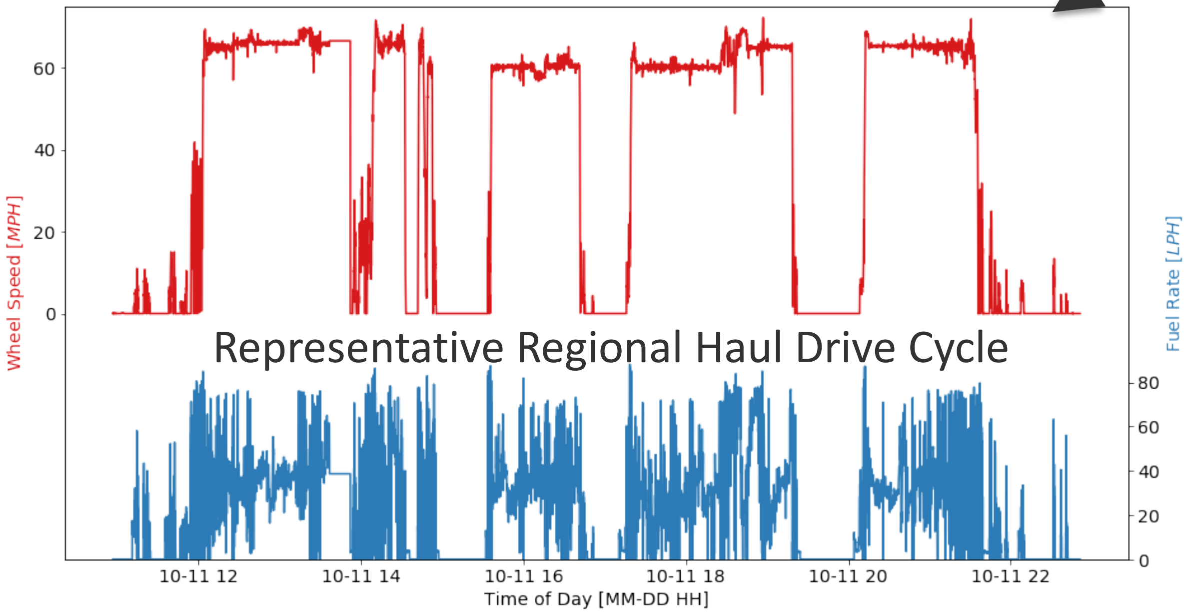
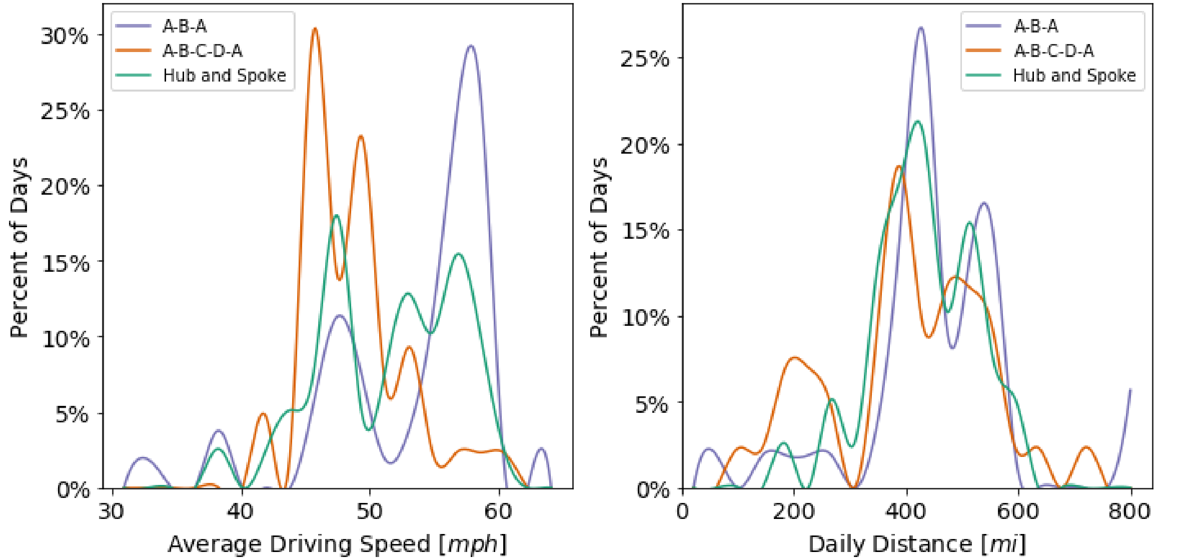
Duty Cycle

- Average driving speeds ~ 50 mph
- Daily average distance = 430 miles
- Max daily distance = 820 mi
- **Challenging for electrification**
  - **Long distances – Lots of energy**
  - **High speed (drag) – Limits energy recapture**



All Speed Profiles





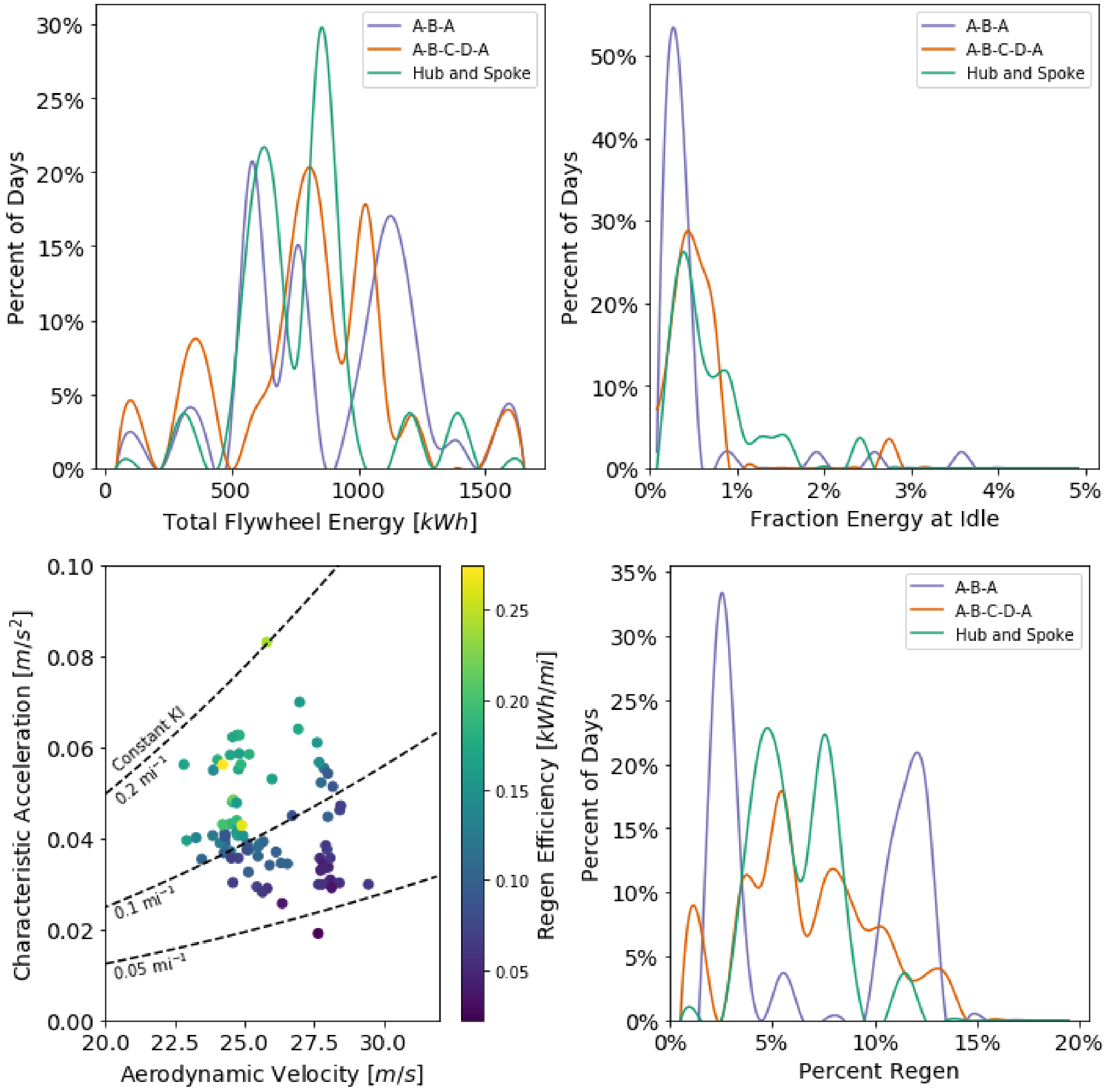
All Trips / All Routes by Route Type

Propulsion Energy

$$P_{road} = mav + mgsin(\theta)v + mgC_{rr}\cos(\theta)v + C_d\ Av^3$$

- Daily avg. energy statistics (ECM)
  - Daily avg. brake energy: 744 kWh
  - Average idle energy: 6.6 kWh
    - 0.92 gal/day
  - **% Energy spent at idle: 0.9%**
    - **Limited EV energy reduction at idle**

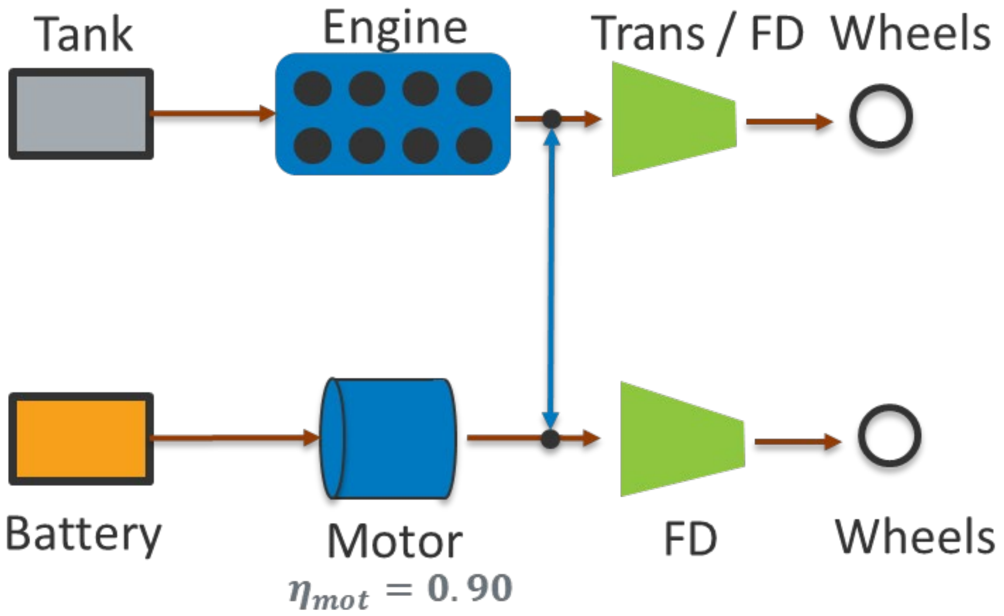
- EV power model based on road-load equation
  - Road grade (θ) - TomTom database
  - Cap regen @ max power - 300 kW
  - Mass(m) – From vehicle or estimated
  - **Avg. day energy recapture through regen**
    - **ABA: 47 kWh**
    - **ABCDA: 58 kWh**
    - **Hub and Spoke: 44 kWh**

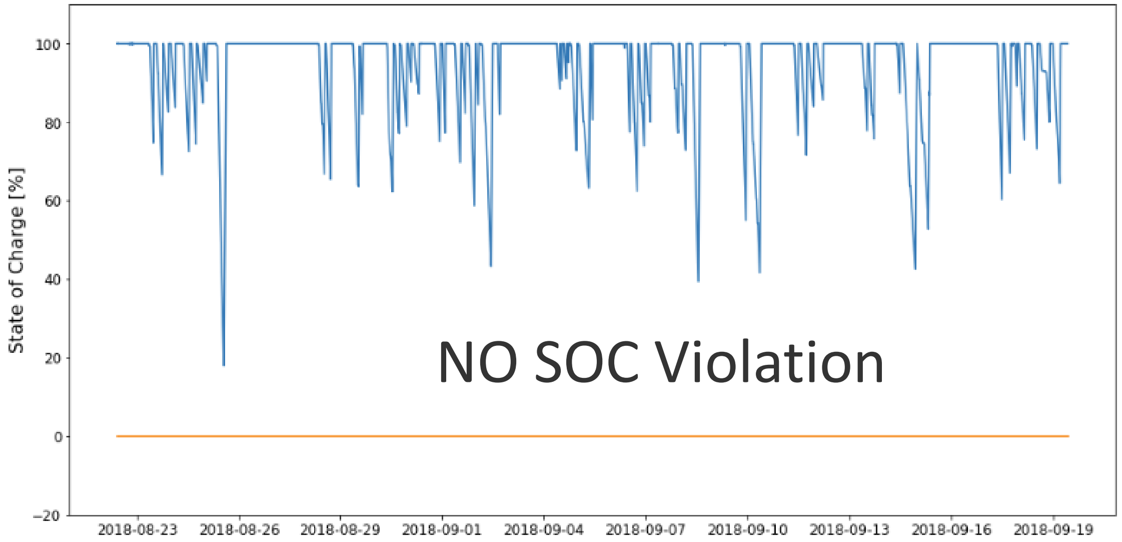


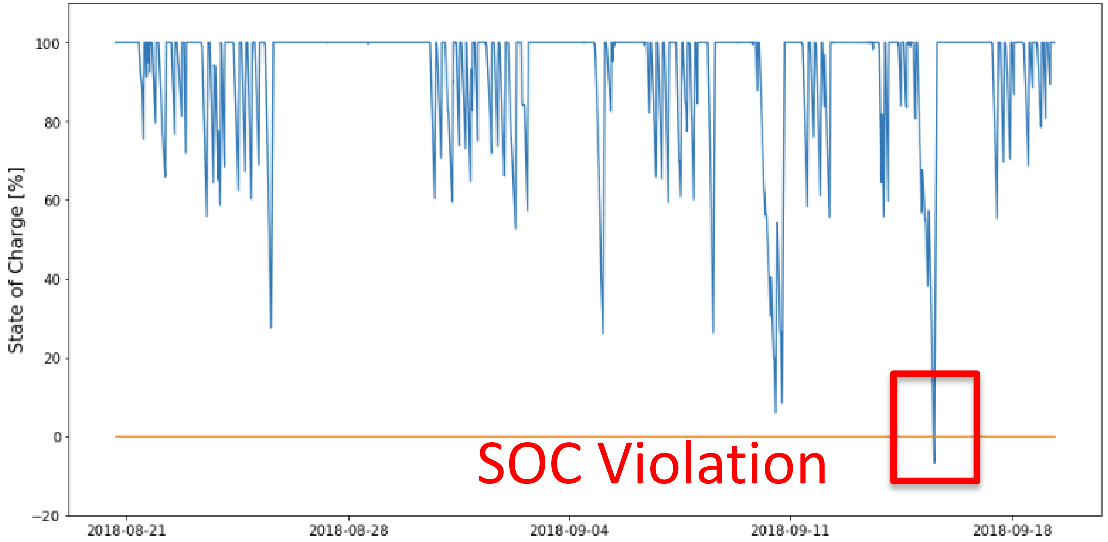
Simple EV Model to Estimate SOC Range During Operation

Simple model

- Swapped engine for motor
- Assume 90% of energy makes it to wheels

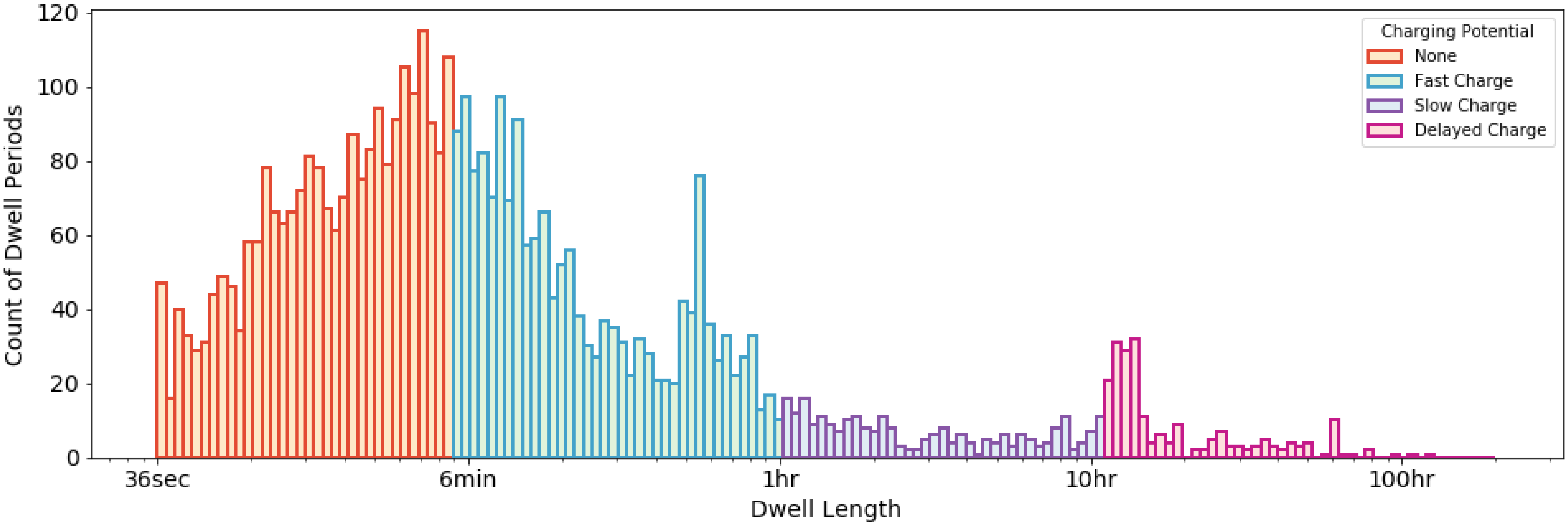






Charging Opportunities

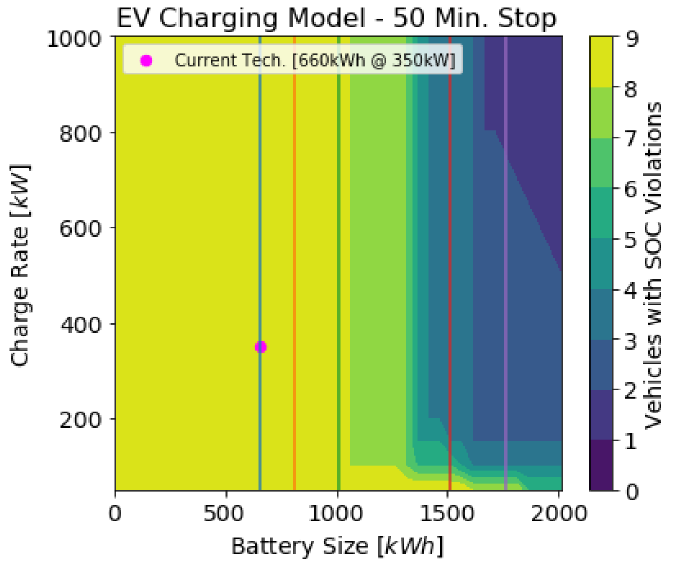
- Charging opportunities exist throughout the day (dwell periods)
  - Majority are short stops with no charging potential (5 minutes to 30 Min)
  - Fast charging (1+MW) may be an option for 30 min or longer
  - Slow/overnight charging opportunities exist, but may be limited (**current technology**)

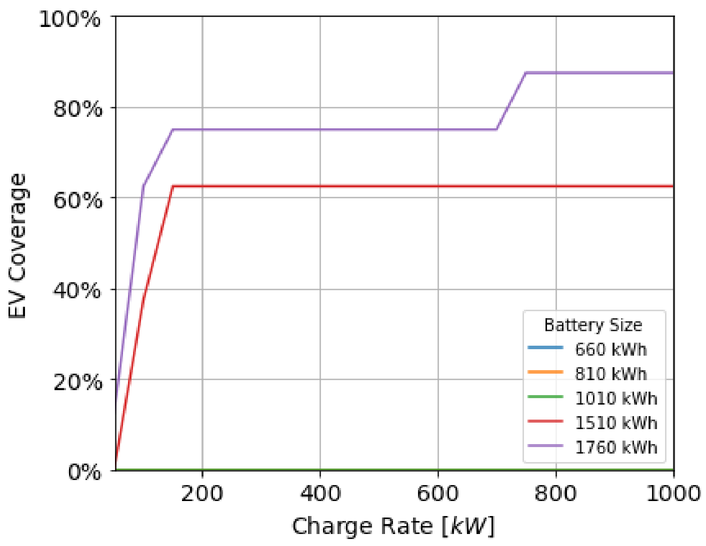


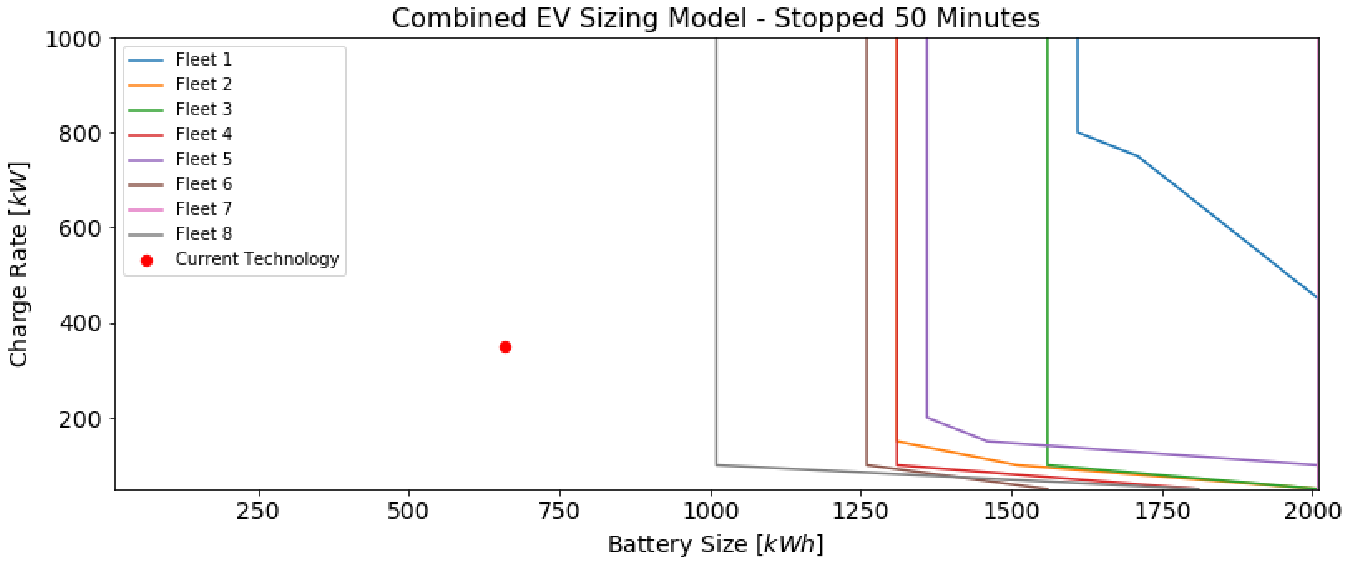
Scenario 1: Depot Charging

- Assumptions – Depot charging
  - Charges when stopped for > 50 min
  - 90% conversion eff.
    - No Regen
  - No energy used when stopped
  - No AC/heating
  - Current tech (electric bus):
    - 350 kW charging
    - 660 kWh battery

Bigger batteries are needed to complete recorded trips if charging solely at the truck depot.





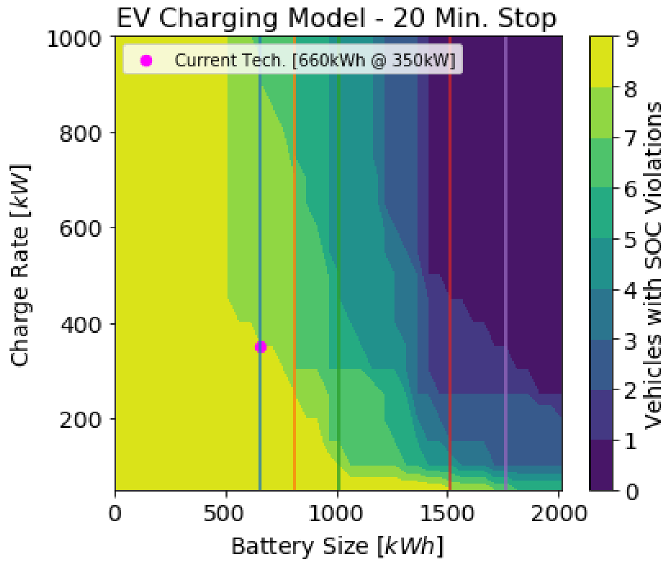


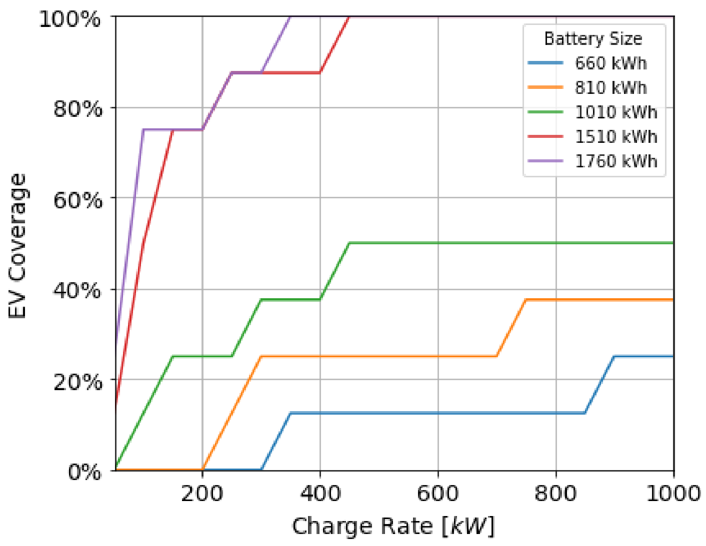
Scenario 2: On Route Charging

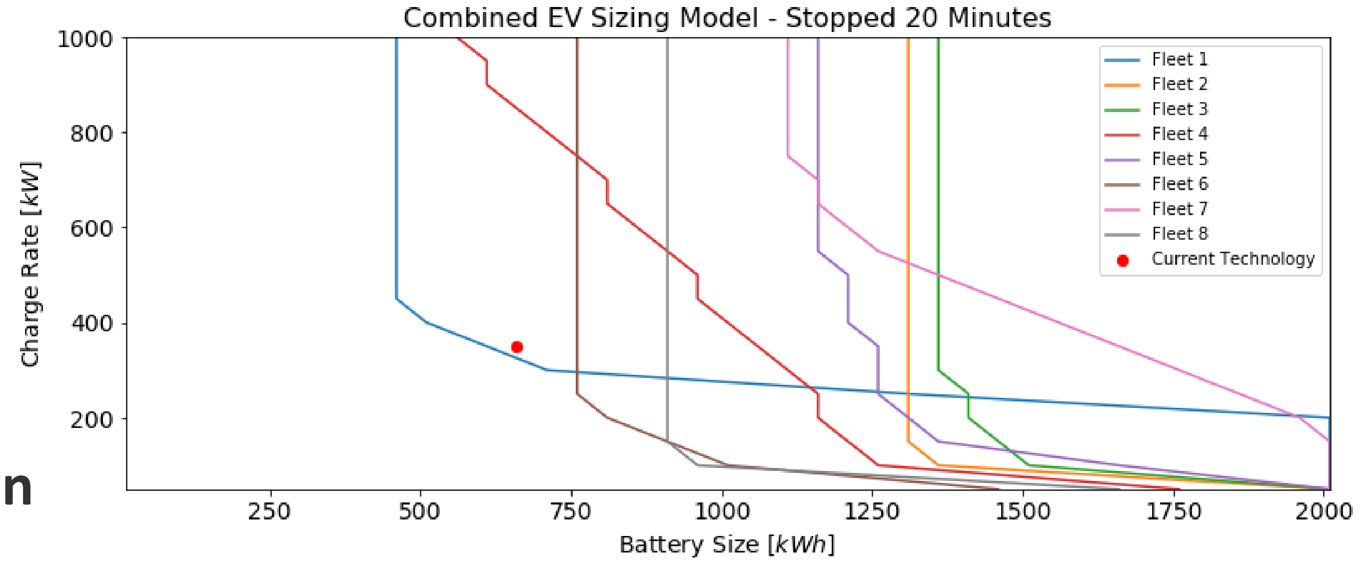
- Assumptions – On-route charging
  - Charges when stopped for > 20 min
  - 90% conversion eff.
    - No Regen
  - No energy used when stopped
  - No AC/heating
  - Current tech (electric bus):
    - 350 kW charging
    - 660 kWh battery

On-route charging can enable high penetration of electric tractors

Advances in technology or changes in operation are needed for full electrification



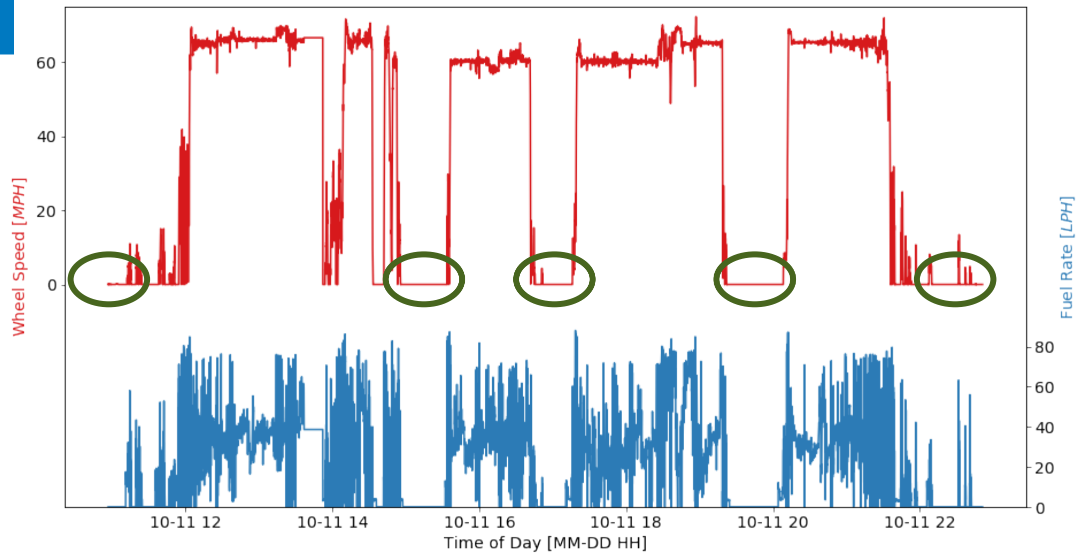


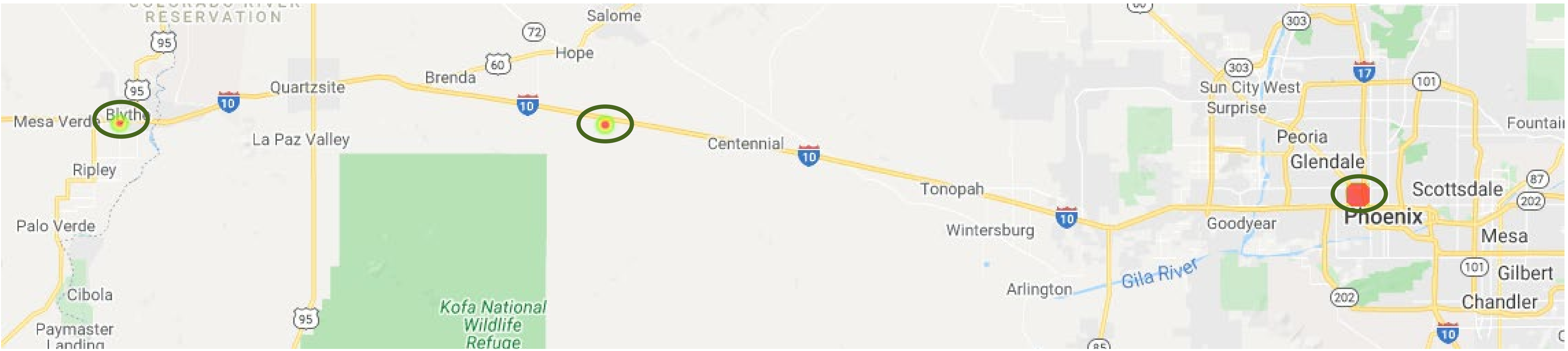


On-Route Charging Needs

Using 1+ MW "Fast Fill" technology

- Example route is A-B-A operation
- 660 kWh battery
  - Charge at start and end
  - Charge midway at existing stop





Price and Emissions

Fuel economy benefit of EV

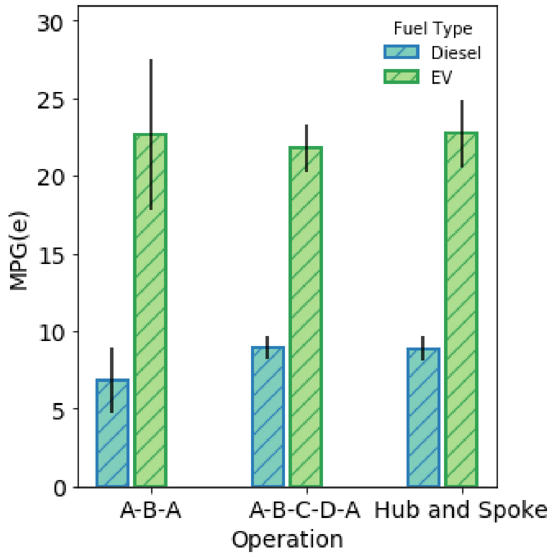
- A-B-A: **3.3X** improvement
- A-B-C-D-A: **2.4X** improvement
- Hub & Spoke: **2.6X** improvement

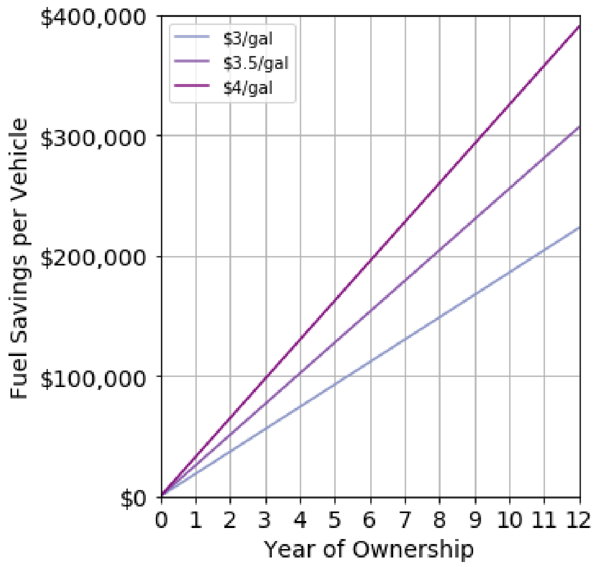
Price

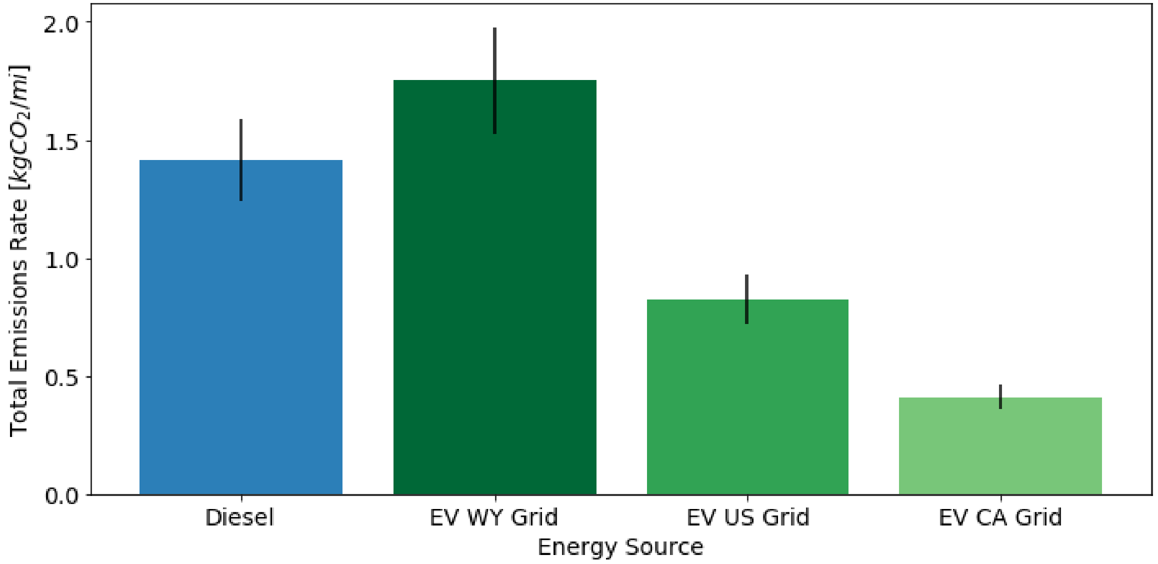
- Assume $0.12/kWh

Emissions benefit (depends where charged)

- Assumptions
  - All carbon → CO_2 (10.1 kg/Gal)
  - Diesel production: 1.84 kgCO_2/Gal
  - US avg. grid: 0.448 kgCO_2/kWh
  - CA grid: 0.223 kgCO_2/kWh
  - WY grid: 0.952 kgCO_2/kWh







Thank You

www.nrel.gov

Andrew Kotz – andrew.kotz@nrel.gov

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Findings of Ballard's whitepaper for HFCEVs on RoLR routes

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Alan Mace

Market Manager

Ballard Power Systems

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Fuel Cell Trucks go the Distance

Alan Mace

August 2020

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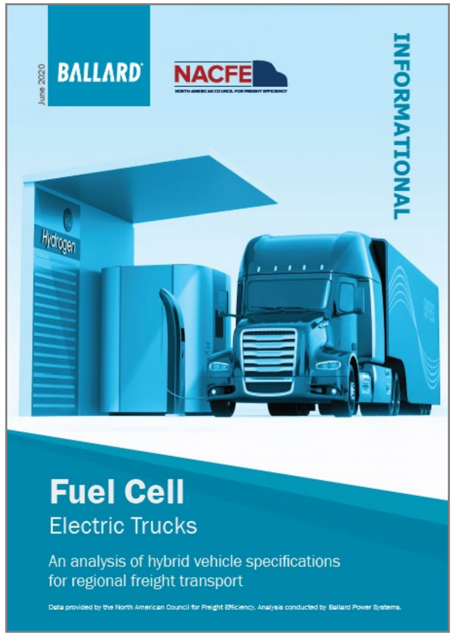


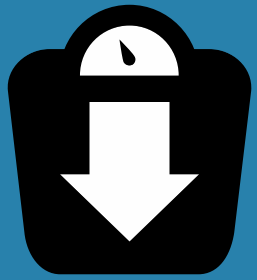
https://info.ballard.com/fuel-cell-electric-trucks

Evaluation of Fuel Cell Technology for HD Regional Haul Trucks

Full-service Regional Haul trucks will be powered by Fuel Cells

Power to maintain speed on demanding routes

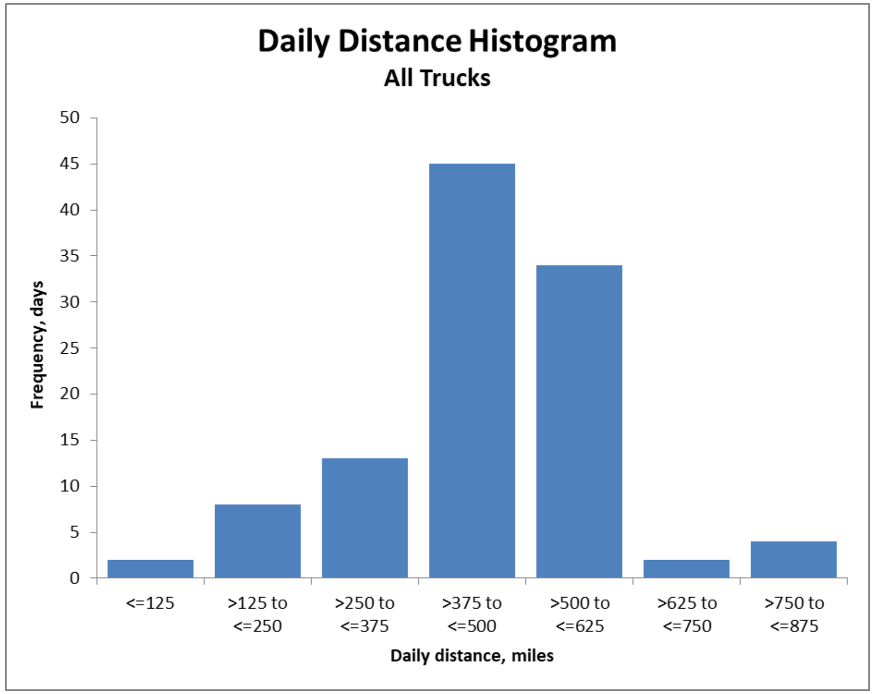
Proven range and route flexibility



High energy density to maximize payload

Rapid refueling ensures high truck utilization

Regional Haul
Daily Range Requirement

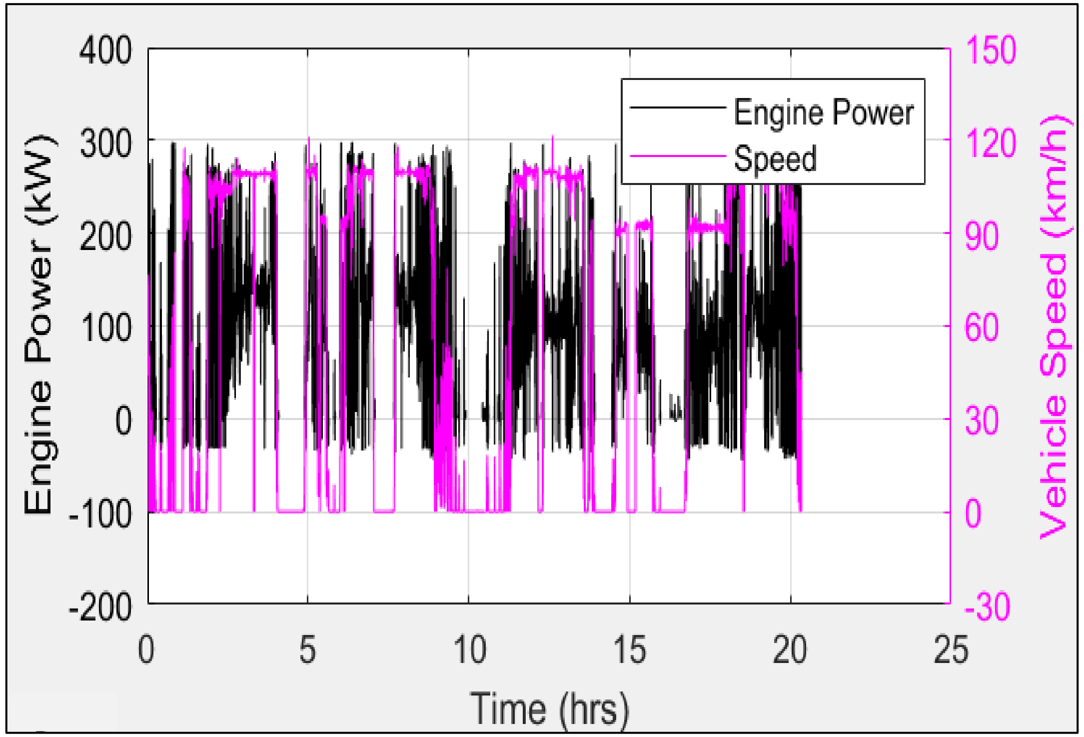


Daily Range, mile	Truck 1	Truck 2	Truck 4	Truck 5	Truck 6	Truck 7	Truck 10
Minimum	370	193	348	79	261	139	216
Average	510	402	461	406	386	414	398
Maximum	819	510	596	714	413	525	503

Summary all data:

- Avg. distance/day 441 mile (712km)
- Max. distance/day 819 mile (1,321km)

Regional Haul Utilization Requirement



- Most daily usage is between 10 – 20 hours/day
- Several instances of > 20 hour/day operation
- A few instances of 24 hour/day operation
- Often a bi-modal distribution: 9 hours – break - 9 hours
- Variability and Unpredictability

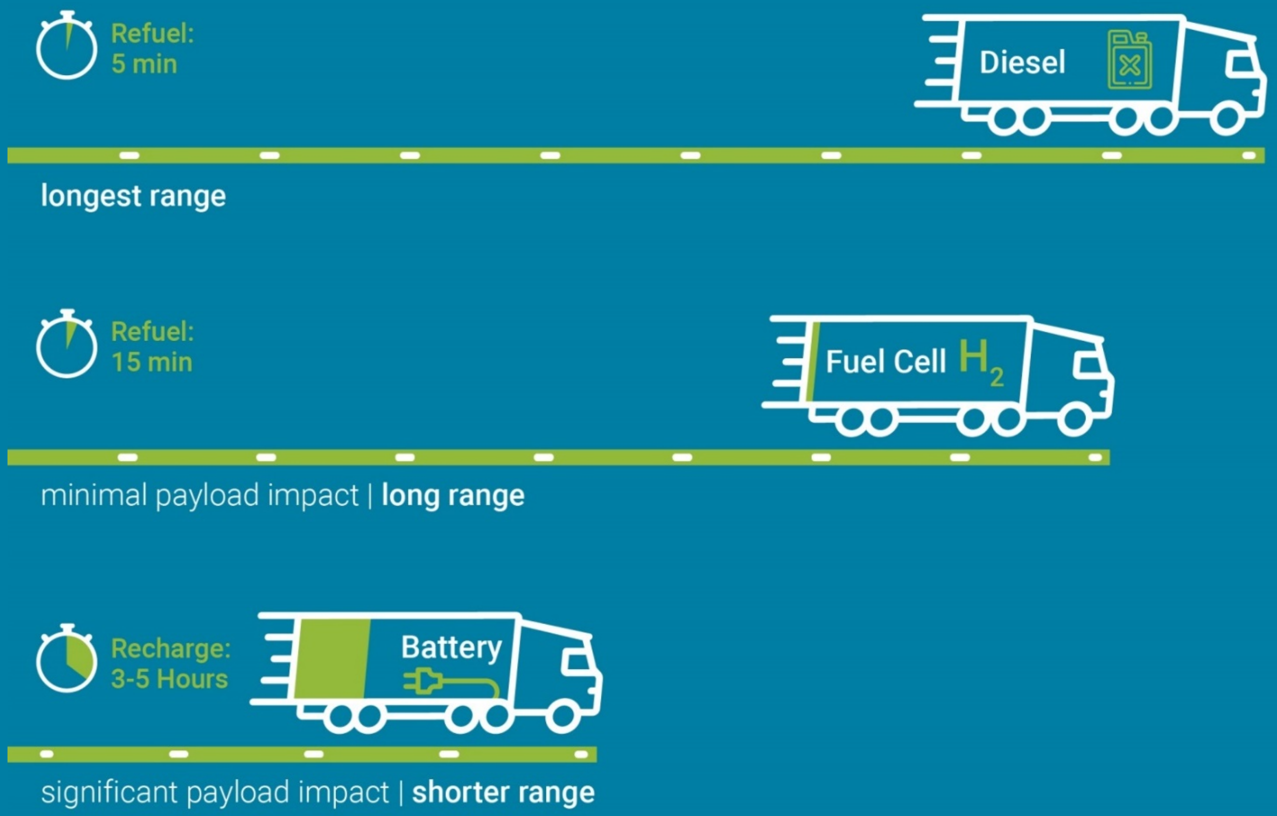
Regional Haul Payload Requirement

- Some trucks ran at maximum load, some returned empty trailers during their routes
- Estimated average payload weight = 24,679 lbs. (11,218kg)

Electrification without impact on operation & profitability

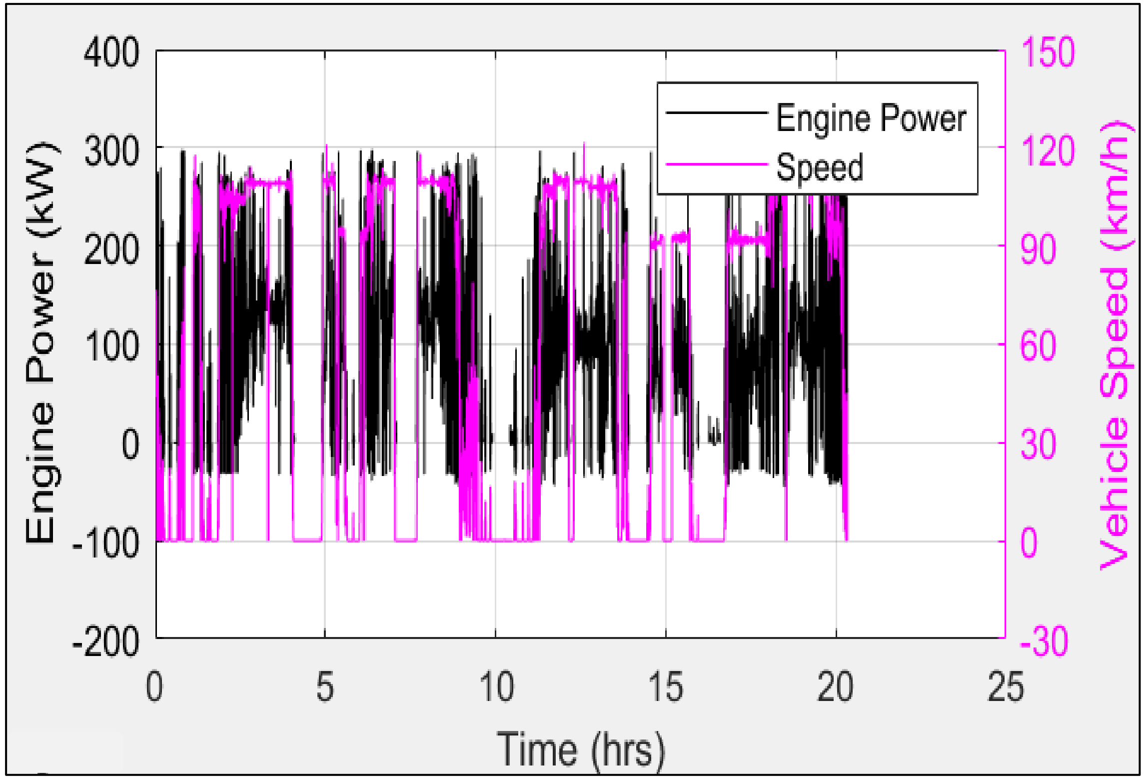
- Fuel cell trucks can haul a similar payload to a diesel truck
  - Future fuel cell truck weight reductions through lower weight storage tanks and improved integration
- Fuel cell trucks are refueled quickly to maximize revenue
  - Battery recharging downtime prevents full utilization of the truck

Fuel Cell Trucks: The Best Zero-Emission Alternative to Diesel



Regional Haul Power Requirement

- Modeled engine power requirements consistently up to 300kW (400HP) or more
- For a fuel cell–battery hybrid architecture, fuel cell power requirements of 200-300kW (270-400HP) with batteries ~20–30kWh are required to meet the duty cycle requirements.



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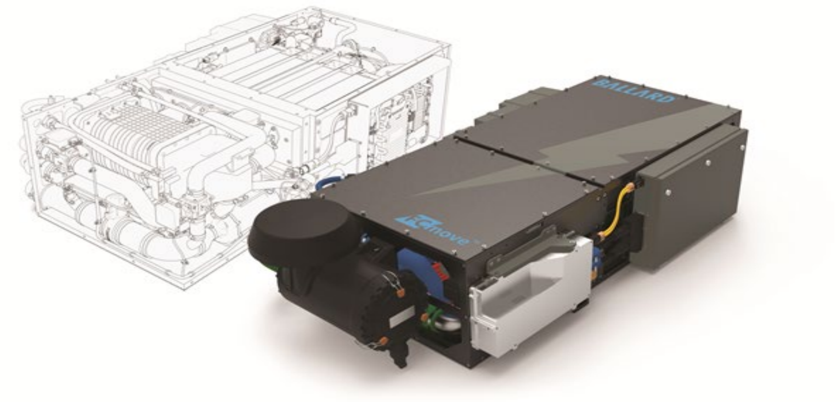

Zero Emission Truck Comparison

	Fuel Cell Electric Truck	Battery Electric Truck
Design	300kW Fuel cell, 23kWh battery, 80kg H2	1185kWh battery
Range	450 mile	
Utilization	Refuels < 20 minutes 1 fuel station needed at depot or along the daily route	Recharging: 8 hours at 120kW rate 3 hours at 350kW rate
Payload	~5,500 lbs less than diesel truck	~17,350 lbs. less than diesel truck

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Implementation

- Regulations requiring zero emissions
- Cost of technology and fuel
- Initial focus on fleets
- Initial public support for infrastructure with strategic, thoughtful fuel station roll-out
- Regional clusters with connecting corridors
- Scale

Hydrogen

- 4.5 EUR/kg (at the pump) due to scale, utilization and lower energy cost

-60%

Tank and System

- Volume scale up to 150k
- Technological improvements

-66%

Fuel Cell Stack

- Volume scale up from 1k to 150k

-75%

McKinsey & Company - Path to Hydrogen Competitiveness (2020)

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Partnerships and investment are accelerating

There are ~3,400 fuel cell trucks in operation worldwide today

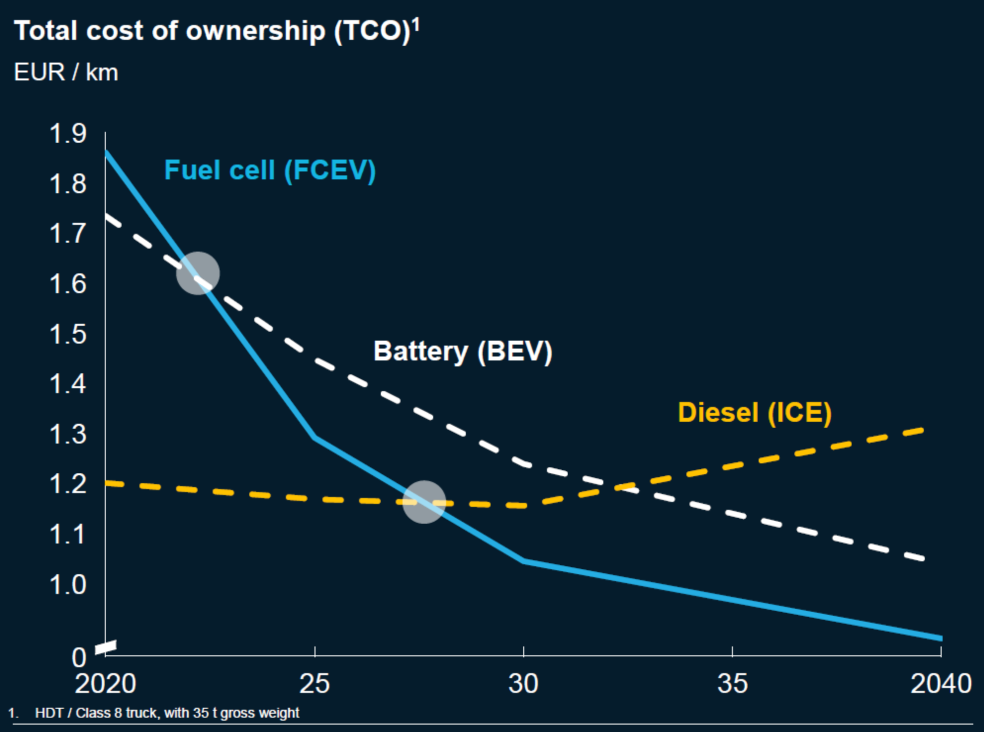
- 3,350 of those trucks are in operation in China (3-9t trucks) for urban deliveries
  - 65% of them powered by Ballard technology
- 50+ trucks in various demonstration projects in US and Europe with truck ranging from Class 4-8 vehicles to 290-tonne mining trucks
- Announced projects: 1,600 fuel cell truck deployment by Hyundai in Switzerland and 800 Nikola fuel cell trucks for Anheuser Busch in the US



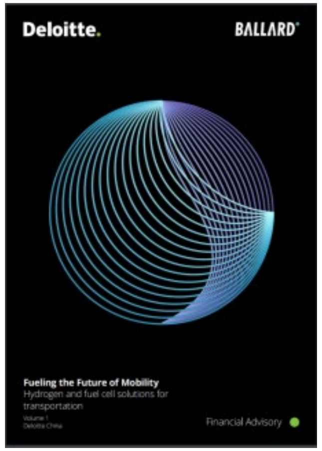


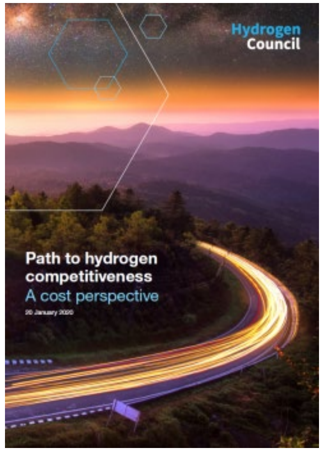


Fuel cell trucks meet the requirements for Regional Haul



McKinsey & Company - Path to Hydrogen Competitiveness (2020)





"**In less than 10 years, it will become cheaper to run a fuel cell electric vehicle** than it is to run a battery electric vehicle or an internal combustion engine vehicle for certain commercial applications."

Deloitte/Ballard – Fueling the Future of Mobility (2020)
McKinsey & Company - Path to Hydrogen Competitiveness (2020)

BALLARD

BALLARD BY THE NUMBERS

40 YEARS	900 employees	1,400 patents & applications	25 years Nasdaq 27 years TSX publicly listed Company	WEICHAI AngloAmerican NISSHINBO 大洋电机 BROAD-OCEAN 4 strategic shareholders
870+ transit buses	2,200+ trucks	4 TRAIN projects on track	5 SHIPS in development	12,000 forklifts in operation
$80million automobile stack development program	670 MW fuel cell products delivered	>5.5million MEAs produced	>30million kilometers in operation	>30,000hours operation of fuel cell stack in London buses

We deliver fuel cell power for a sustainable planet

Thank you

www.ballard.com

Panelist Questions & Answers

NACFE

Mike Roeth
Executive Director
North American Council for Freight Efficiency

NREL

Andrew Kotz, Ph.D.
Commercial Vehicle Research Engineer
National Renewable Energy Laboratory

BALLARD

Alan Mace
Market Manager
Ballard Power Systems

ACT NEWS

RUN ON LESS BY NACFE

NACFE Resources

- Emerging Technology Guidance Reports
  - https://nacfe.org/report-library/guidance-reports/
- Run on Less Regional Report
  - https://nacfe.org/run-on-less-regional-report/
- NACFE/NREL on Battery Electric Powertrains for Class 8 Regional Haul Freight Based on NACFE Run-On-Less
  - https://nacfe.org/wp-content/uploads/2020/06/EVS33_Mihelic_ID257_NACFE_NREL_PrePub_Download.pdf
- Ballard/NACFE on Fuel Cell Electric Trucks: An analysis of hybrid vehicle specifications for regional freight transport
  - Fuel Cell Electric Trucks: An analysis of hybrid vehicle specifications for regional freight transport

Other Resources

- Ballard
  - https://www.ballard.com/
- National Renewable Energy Laboratory
  - https://www.nrel.gov/transportation/index.html

Thank You!

What did you think of the webinar? Please fill out our 30 second survey.

A recording of today's webinar will be posted on the ACT News website and you will be emailed a link early next week.