Keeping It Real: Regional Haul, Zero-Emission, Heavy-Duty Tractors
August 6, 2020
Keeping It Real: Regional Haul, Zero-Emission, Heavy-Duty Tractors

August 6, 2020
Moderated by Rick Mihelic
Director Emerging Technologies, NACFE
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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 are promising
• 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
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

Mike Roeth
Executive Director
North American Council for Freight Efficiency

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

Alan Mace
Market Manager
Ballard Power Systems
Learnings from the Run on Less Regional

Mike Roeth
Executive Director
North American Council for Freight Efficiency
Technology Day Webinar Series

Webinar 1: October 8 - Hydrogen
Is Hydrogen a Viable Truck Fuel?
Time: 11 am PT / 2 pm ET

Webinar 2: October 15 - Connectivity
How Can Connectivity Improve Trucking Efficiency?
Time: 11 am PT / 2 pm ET

Webinar 3: October 23 - Battery Electric Vehicles
How Far Will Commercial Battery Electric Vehicles Go?
Time: 11 am PT / 2 pm ET

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NACFE
North American Council for Freight Efficiency
Growth in Regional Haul is Good

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

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: 8
ROL Regional Possible: 5.5
Future Potential: 1

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY
Growth in Regional Haul is Good
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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
### REGIONAL HAUL DUTY CYCLE DEFINITIONS

<table>
<thead>
<tr>
<th>RoLR Stated Duty Cycles</th>
<th>Duty Cycles</th>
<th>Definition</th>
<th>RoLR Fleets</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-B-A</td>
<td>Shuttles</td>
<td>Short multiple runs &lt;150 round trip</td>
<td>Hirschbach</td>
</tr>
<tr>
<td></td>
<td>Dedicated</td>
<td>150 to ~400 miles RT</td>
<td>Hogan</td>
</tr>
<tr>
<td></td>
<td>Dedicated Fast Turn</td>
<td>Full 1/2 day drive out ~500 miles RT</td>
<td>SEFL, UPS</td>
</tr>
<tr>
<td>Hub and Spoke</td>
<td>Hub and Spoke</td>
<td>A-B with different place each day</td>
<td>C&amp;S, Schneider</td>
</tr>
<tr>
<td>A-B-C-D-A</td>
<td>City</td>
<td>Multiple drops, low miles</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Diminishing Load</td>
<td>Drop offs only</td>
<td>JB Hunt</td>
</tr>
<tr>
<td></td>
<td>Milk Run</td>
<td>Drops and pickups later in the run</td>
<td>Meijer, PepsiCo, Ploger</td>
</tr>
</tbody>
</table>
Efficiency Opportunity

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

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Conclusions from NREL’s work on electrifying the RoLR routes
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
  – 298 million tons CO$_2$/year

What would it take to electrify?
• Battery Size
• Charge Rate
• Infrastructure

• 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Miles of Data</th>
<th>Gallons Used</th>
<th>Hours of Operation</th>
<th>Vehicle Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>58,090</td>
<td>6,434</td>
<td>1,921</td>
<td>142</td>
</tr>
</tbody>
</table>

ROLR Overview Stats
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

Representative Regional Haul Drive Cycle
Propulsion Energy

- 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 ($\theta$) - 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

\[ P_{\text{road}} = m a v + m g \sin(\theta) v + m g C_{rr} \cos(\theta) v + C_d A v^3 \]
Simple EV Model to Estimate SOC Range During Operation

Simple model

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

\[ \eta_{mot} = 0.90 \]
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 $\rightarrow$ 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
Findings of Ballard’s whitepaper for HFCEVs on RoLR routes

Alan Mace
Market Manager
Ballard Power Systems
Fuel Cell Trucks go the Distance

Alan Mace

August 2020
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

https://info.ballard.com/fuel-cell-electric-trucks
## Regional Haul Daily Range Requirement

### Summary all data:
- Avg. distance/day: 441 mile (712km)
- Max. distance/day: 819 mile (1,321km)

<table>
<thead>
<tr>
<th>Daily Range, mile</th>
<th>Truck 1</th>
<th>Truck 2</th>
<th>Truck 4</th>
<th>Truck 5</th>
<th>Truck 6</th>
<th>Truck 7</th>
<th>Truck 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>370</td>
<td>193</td>
<td>348</td>
<td>79</td>
<td>261</td>
<td>139</td>
<td>216</td>
</tr>
<tr>
<td>Average</td>
<td>510</td>
<td>402</td>
<td>461</td>
<td>406</td>
<td>386</td>
<td>414</td>
<td>398</td>
</tr>
<tr>
<td>Maximum</td>
<td>819</td>
<td>510</td>
<td>596</td>
<td>714</td>
<td>413</td>
<td>525</td>
<td>503</td>
</tr>
</tbody>
</table>
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
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.
## Zero Emission Truck Comparison

<table>
<thead>
<tr>
<th></th>
<th>Fuel Cell Electric Truck</th>
<th>Battery Electric Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design</strong></td>
<td>300kW Fuel cell, 23kWh battery, 80kg H2</td>
<td>1185kWh battery</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>450 mile</td>
<td></td>
</tr>
<tr>
<td><strong>Utilization</strong></td>
<td>Refuels &lt; 20 minutes 1 fuel station needed at depot or along the daily route</td>
<td>Recharging: 8 hours at 120kW rate 3 hours at 350kW rate</td>
</tr>
<tr>
<td><strong>Payload</strong></td>
<td>~5,500 lbs less than diesel truck</td>
<td>~17,350 lbs. less than diesel truck</td>
</tr>
</tbody>
</table>
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
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
“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 BY THE NUMBERS

- 40 YEARS
- 900 employees
- 1,400 patents & applications
- 25 years publicly listed Company
- 4 strategic shareholders

- 870+ transit buses
- 2,200+ trucks
- 4 TRAIN projects on track
- 5 SHIPS in development
- 12,000 forklifts in operation

- $80 million automobile stack development program
- 670 MW fuel cell products delivered
- >5.5 million MEAs produced
- >30 million kilometers in operation
- >30,000 hours operation of fuel cell stack in London buses

Power to Change the World®
We deliver fuel cell power for a sustainable planet

Thank you

www.ballard.com
NACFE Resources

• Emerging Technology Guidance Reports
  • [https://nacfe.org/report-library/guidance-reports/](https://nacfe.org/report-library/guidance-reports/)

• Run on Less Regional Report
  • [https://nacfe.org/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

• Ballard/NACFE on 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!

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