System Perspective on Emerging Trends and Freight Truck Sustainability

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How will emerging trends and technologies impact freight truck sustainability?

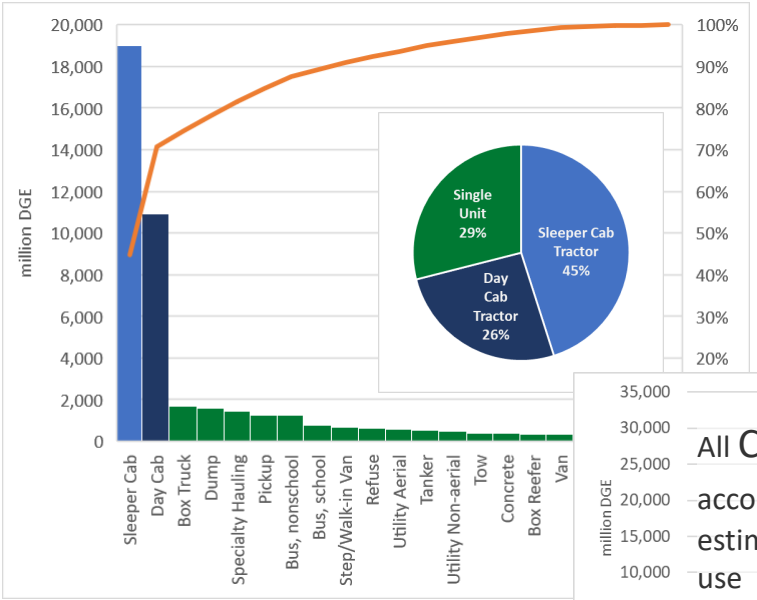
- Energy
- Emissions
- Congestion

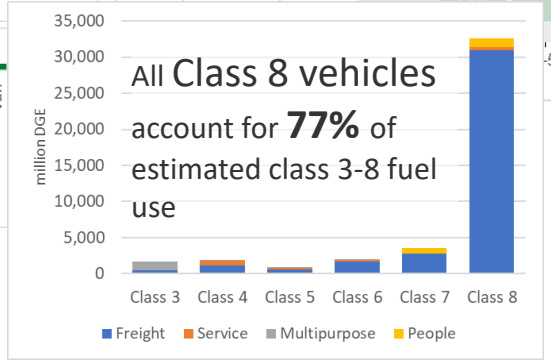
How do we assess possible impacts?

- Analytical framework, modeling
- Data

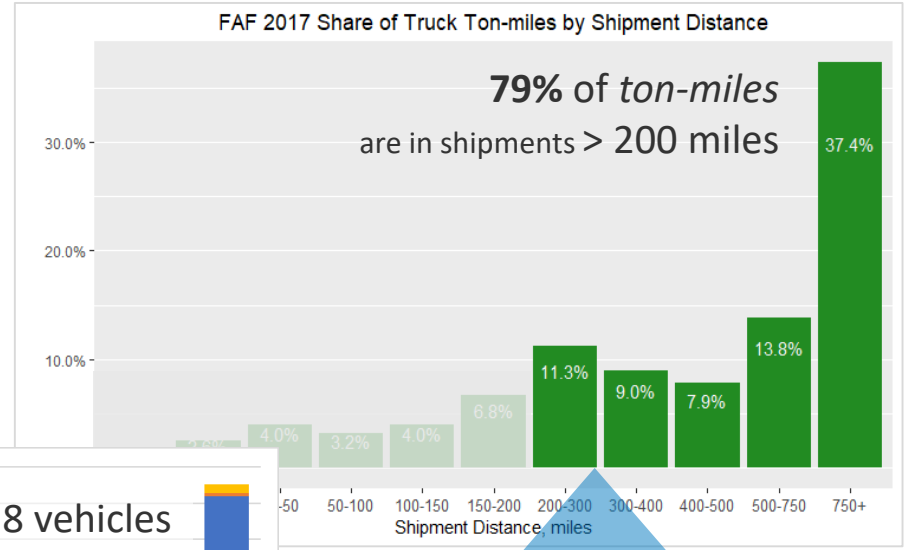
What vehicles account for most national freight truck energy demand and emissions?

Class 7&8 tractors account for **71%** of estimated class 3-8 fuel use





All Class 8 vehicles account for **77%** of estimated class 3-8 fuel use



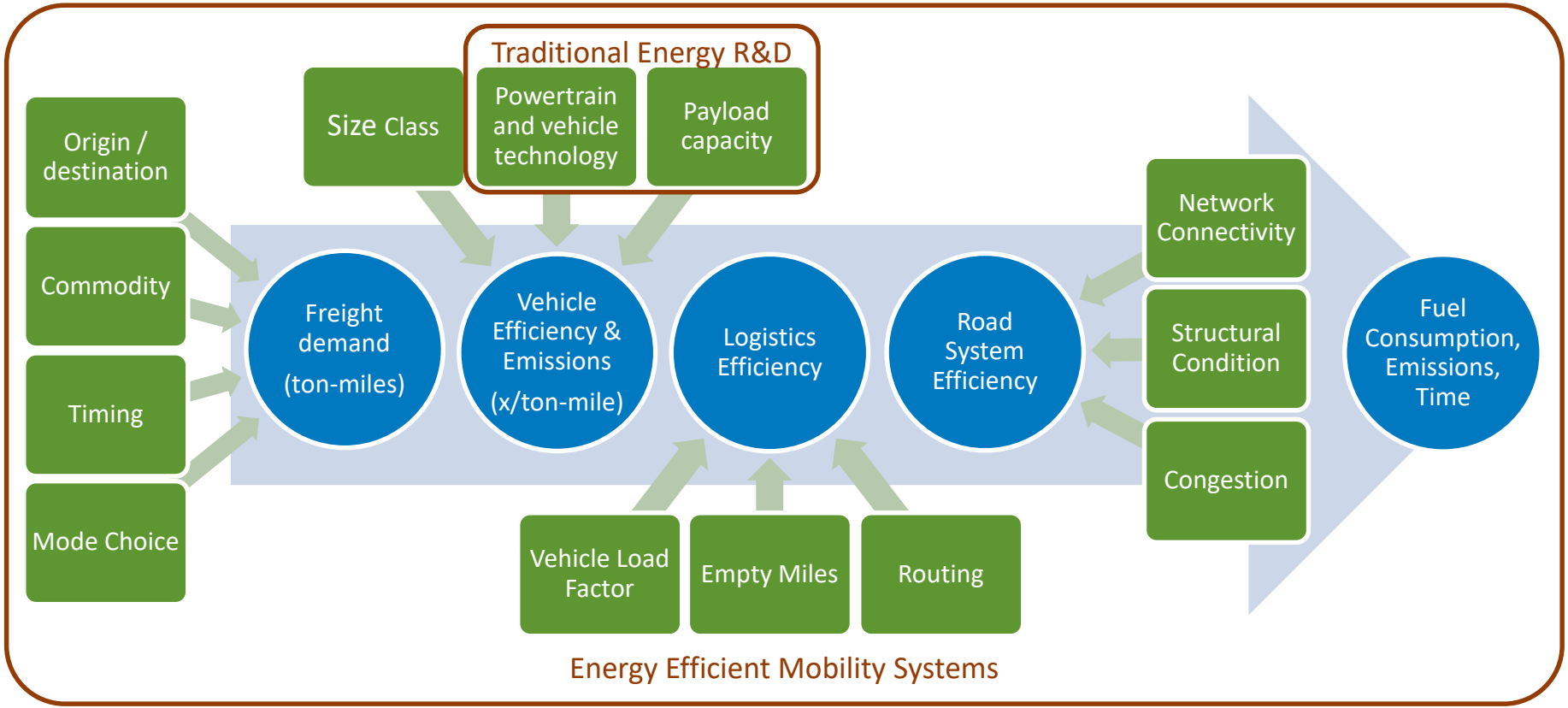
79% of *ton-miles* are in shipments > 200 miles

While >75% of freight truck tonnage is in shipments <200 miles,

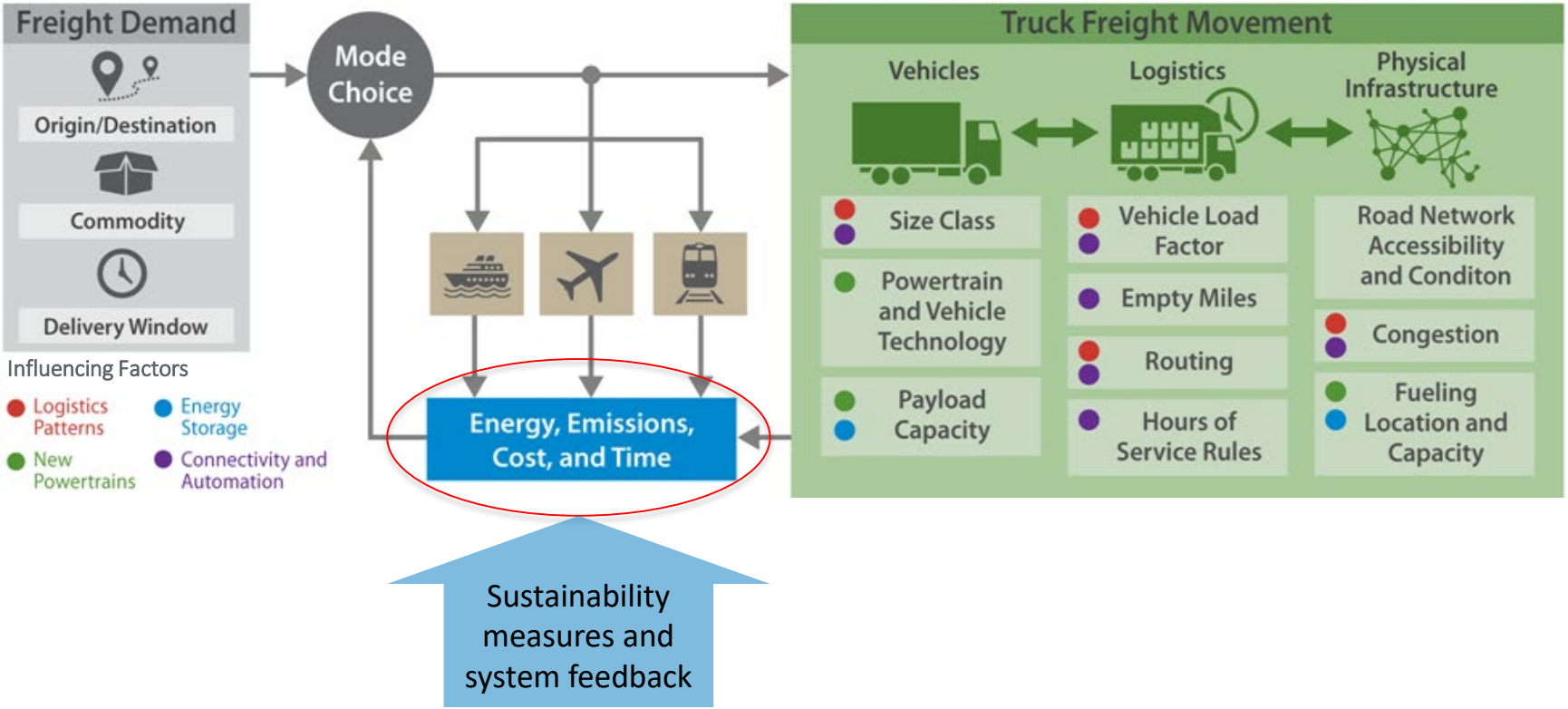
79% of truck ton-miles are in shipments >200 miles.

Data sources:
U.S. DOT, Freight Analysis Framework, Version 4.5
IHS Polk vehicle registrations, 2013
U.S. Census, 2002 VIUS

Freight Truck Sustainability: A Systems Perspective



Analytical Framework



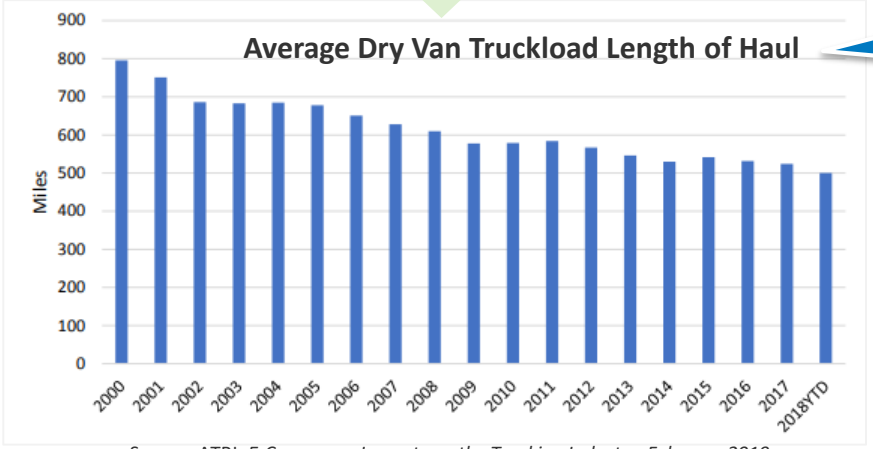
How will emerging trends and technologies effect truck freight sustainability?

Freight Demand	Vehicle Efficiency & Emissions	Logistics Efficiency	Road System Efficiency
• Origin / destination? • Commodity? • Timing? • Mode choice?	• Size Class? • Powertrain and vehicle technology? • Payload capacity?	• Vehicle Load Factor? • Empty Miles? • Routing?	• Network Accessibility? • Structural Condition? • Congestion?

Trend 1: Decreasing length of haul

ATRI credits driver shortage and e-commerce growth as driving forces behind decreasing average length of haul

… though e-commerce was not significant in 2000-2010



Source: ATRI, *E-Commerce Impacts on the Trucking Industry, February 2019*

Why does length of haul matter?

- Technology applicability
- *Range and refueling requirements for new powertrains*
- Truck size selection

What trucks and service categories are changing with e-commerce growth? Other trends?

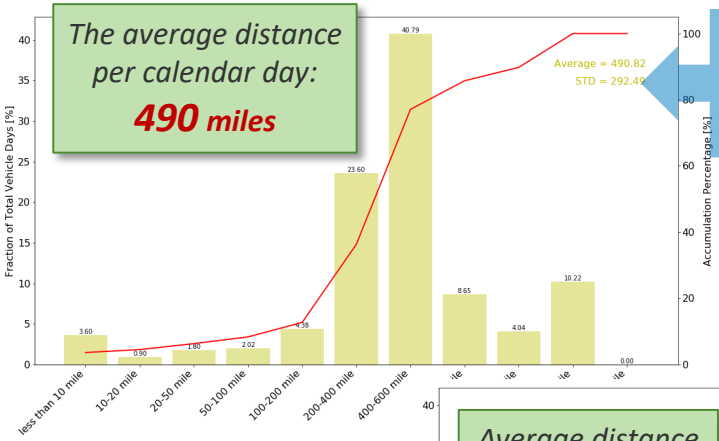
The problem with averages…

Does decreasing *average* length of haul mean there is:

- An increase in demand for shorter trips?
- A decrease in demand for longer trips?
- An overall decrease in the length of trips?

Determining long haul truck range requirements from operational data

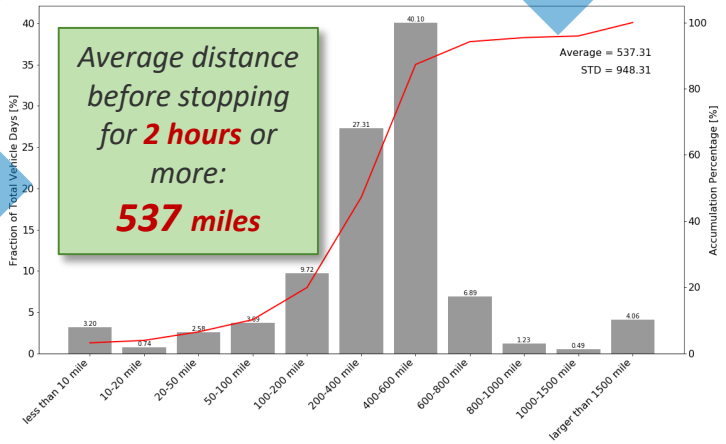
The average distance per calendar day:
490 miles



Calendar days not aligned with operations.

Long right tail:

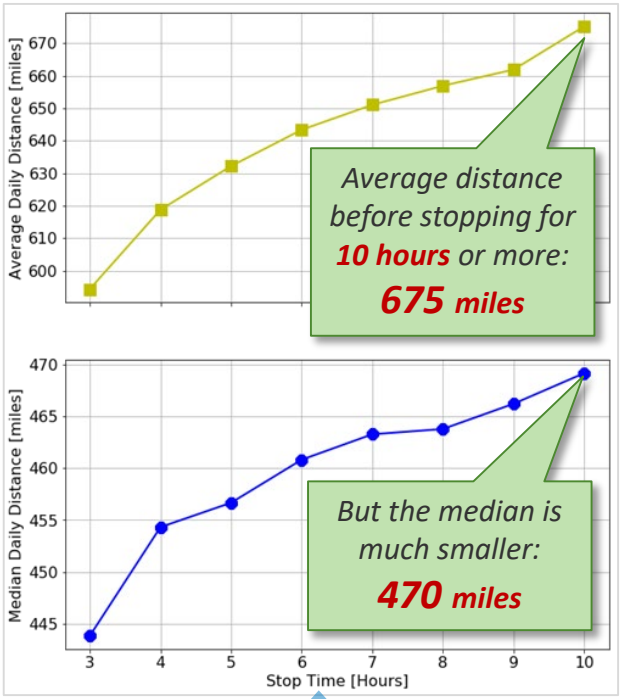
average << 95th %-ile



*Average distance before stopping for **2 hours** or more:*
537 miles

2-hour+ stop may indicate fast-charging opportunity.

Source: Fleet DNA data analysis by NREL

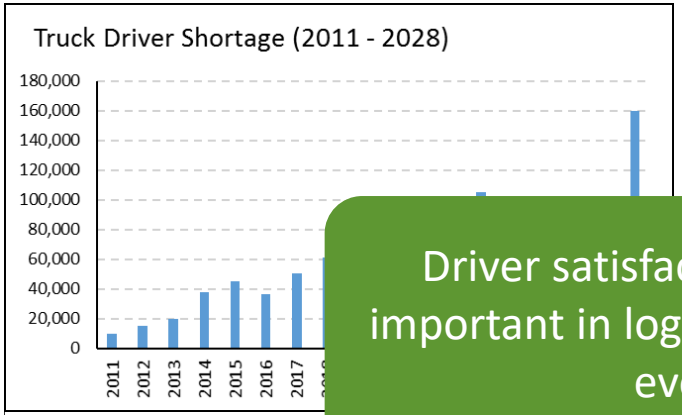


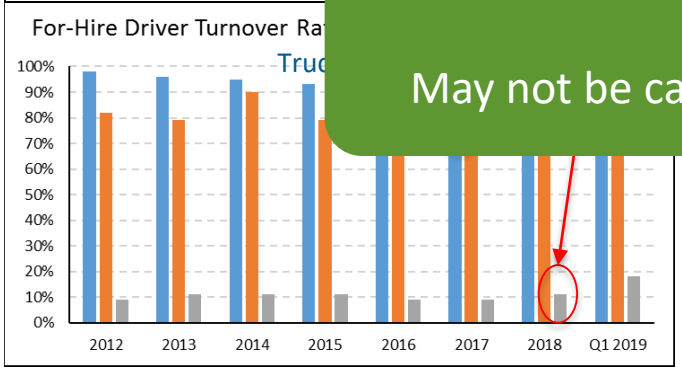
*Average distance before stopping for **10 hours** or more:*
675 miles

But the median is much smaller:
470 miles

10-hour stop is consistent with hours of service rules and overnight charging -- can be long distance with team drivers.

What else is going on in long haul trucking?





Source: ATA Driver Shortage Report 2019

- "Over the next decade, the trucking industry will need to hire roughly 1.1 million new drivers, or an average of nearly 110,000 per year. Replacing retiring truck drivers will be by far the largest factor, accounting for over half of new driver hires (54%). The second largest factor will be industry growth, accounting for 25% of new driver hires."

n above 81% since

r Shortage Report 2019

l (TL) motor freight

which force firms to

cruitment and

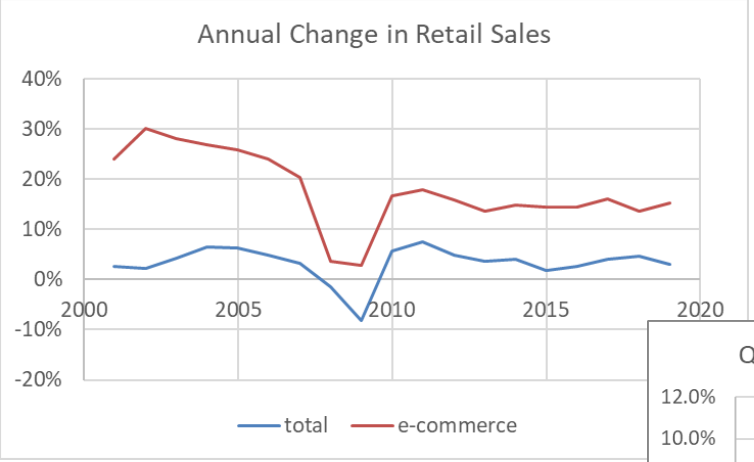
retention when many individuals entering the occupation in this specific part of the trucking industry find the working conditions and earnings to be unattractive

-- Stephen V. Burks and Kristen Monaco, "Is the U.S. labor market for truck drivers broken?," Monthly Labor Review, U.S. Bureau of Labor Statistics, March 2019, https://doi.org/10.21916/mlr.2019.5.

Driver satisfaction and retention is and will be important in logistical change as well as technology evolution and adoption.

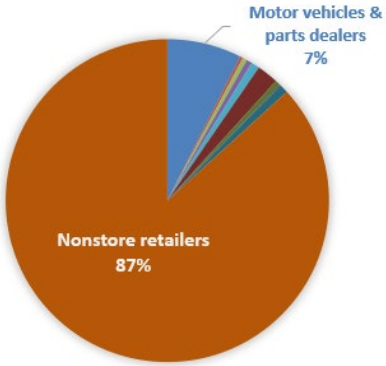
May not be captured in cost / benefit analyses.

Trend 2: E-Commerce
Why is everyone talking about it?



Source: U.S. Census Bureau, Monthly Retail Trade Survey
https://www.census.gov/retail/index.html#ecommerce

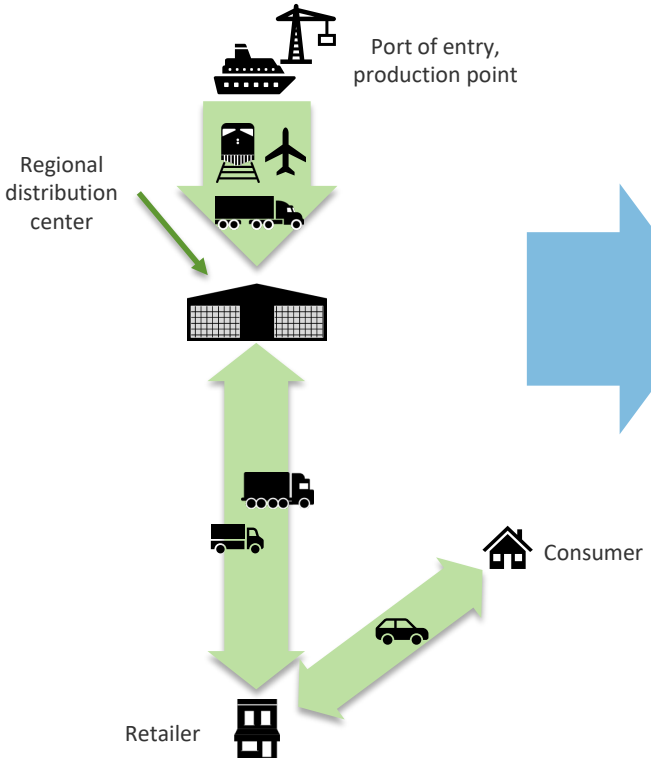
- Since 2000, e-commerce has grown an average of 16.2% per year compared to 3.2% for retail sales overall
- E-commerce is ~11% of retail sales (by value)
- Non-store retailers account for 87% of e-commerce retail sales (no brick and mortar channel)



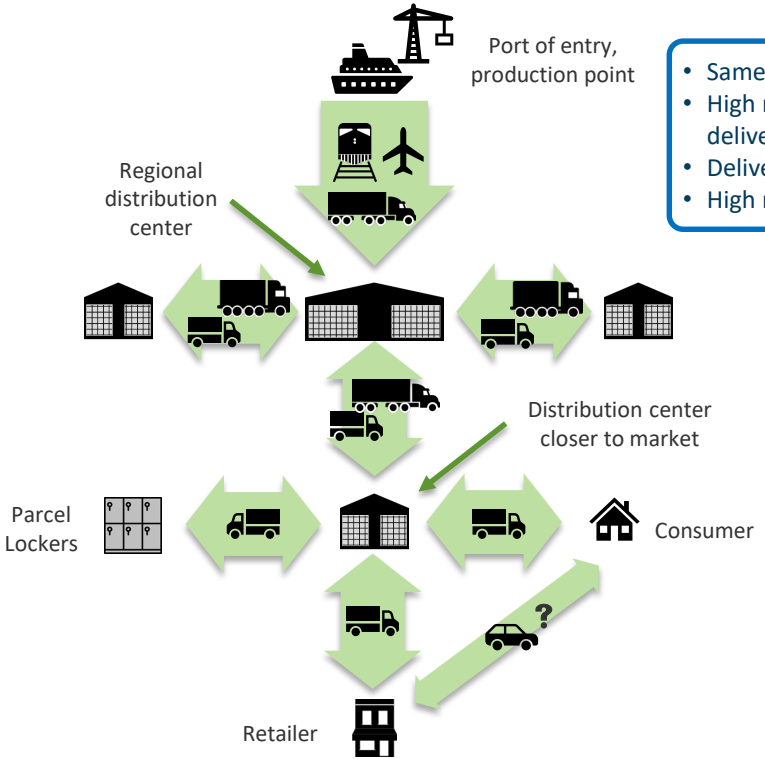
What does growth in e-commerce mean for truck freight energy demand, emissions, and future technology solutions?

E-Commerce Pressure is Driving Logistical Change Throughout Retail

Traditional retail model: single channel via brick and mortar.



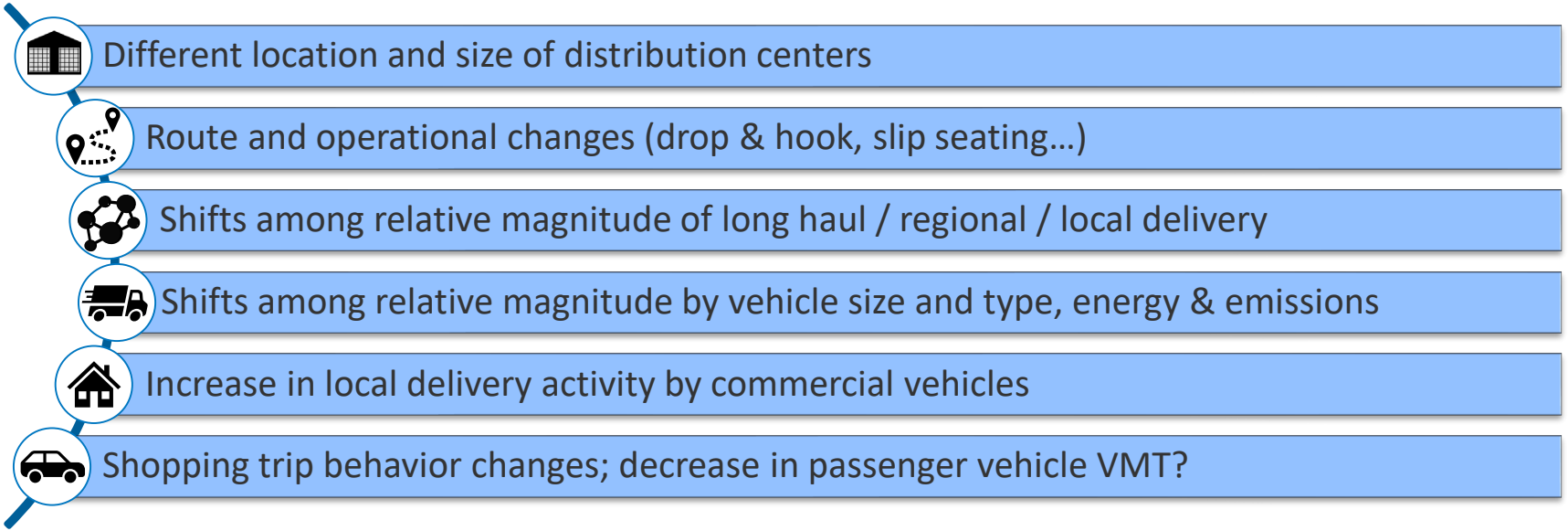
Omni-channel retail model with hub-and-spoke distribution.



- Same day delivery
- High rate of refused delivery
- Delivery location options
- High rate of returns

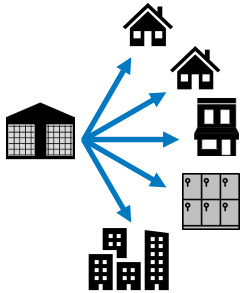
Possible energy impacts due to e-commerce and retailers' response

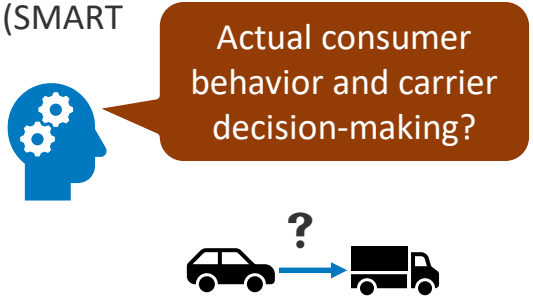
- End-to-end shipment distance may not change much
  - Makes it difficult to analyze impacts from national freight data
- ***How it gets there*** does
- Responses to long haul driver shortage add to these changes



E-commerce: Last Mile Considerations

- Last mile delivery is complex, difficult, and labor intensive
  - Urban congestion
  - On-street unloading
  - Refused delivery requiring re-delivery
  - Insufficient package drop-off space for multi-unit dwellings
- Last mile delivery can be a large portion of shipping costs (trade press reports 28-53%)
- Increased VMT and criteria emissions for larger delivery vehicles versus reductions for personal vehicles?
  - *If* shopping trips are displaced, total VMT and energy may be smaller (SMART Mobility research by ANL)
  - Trip chaining
  - New trips for other purposes
  - Refusal rate
  - Return rate and mode
- Urban vs. rural – differences in impacts, challenge, opportunities, and best solutions

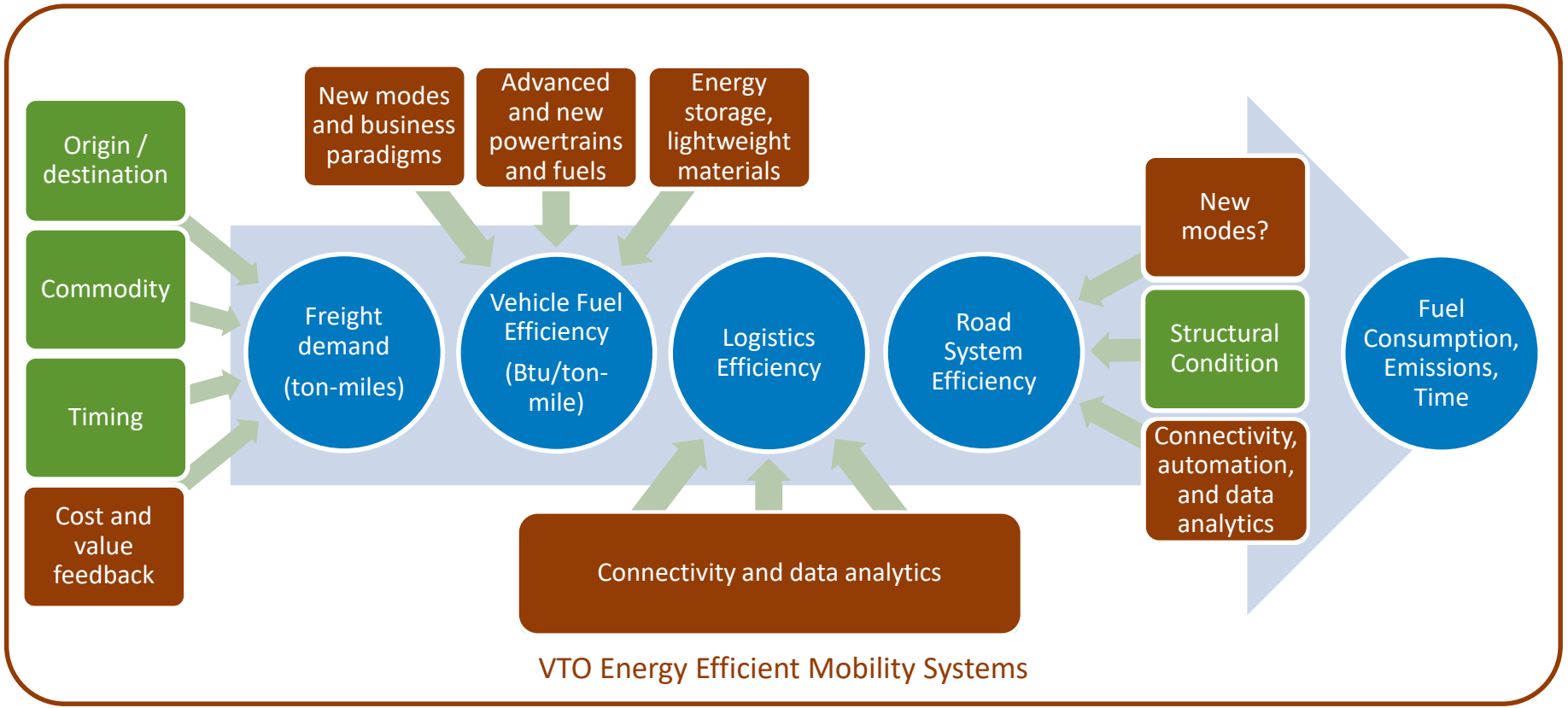




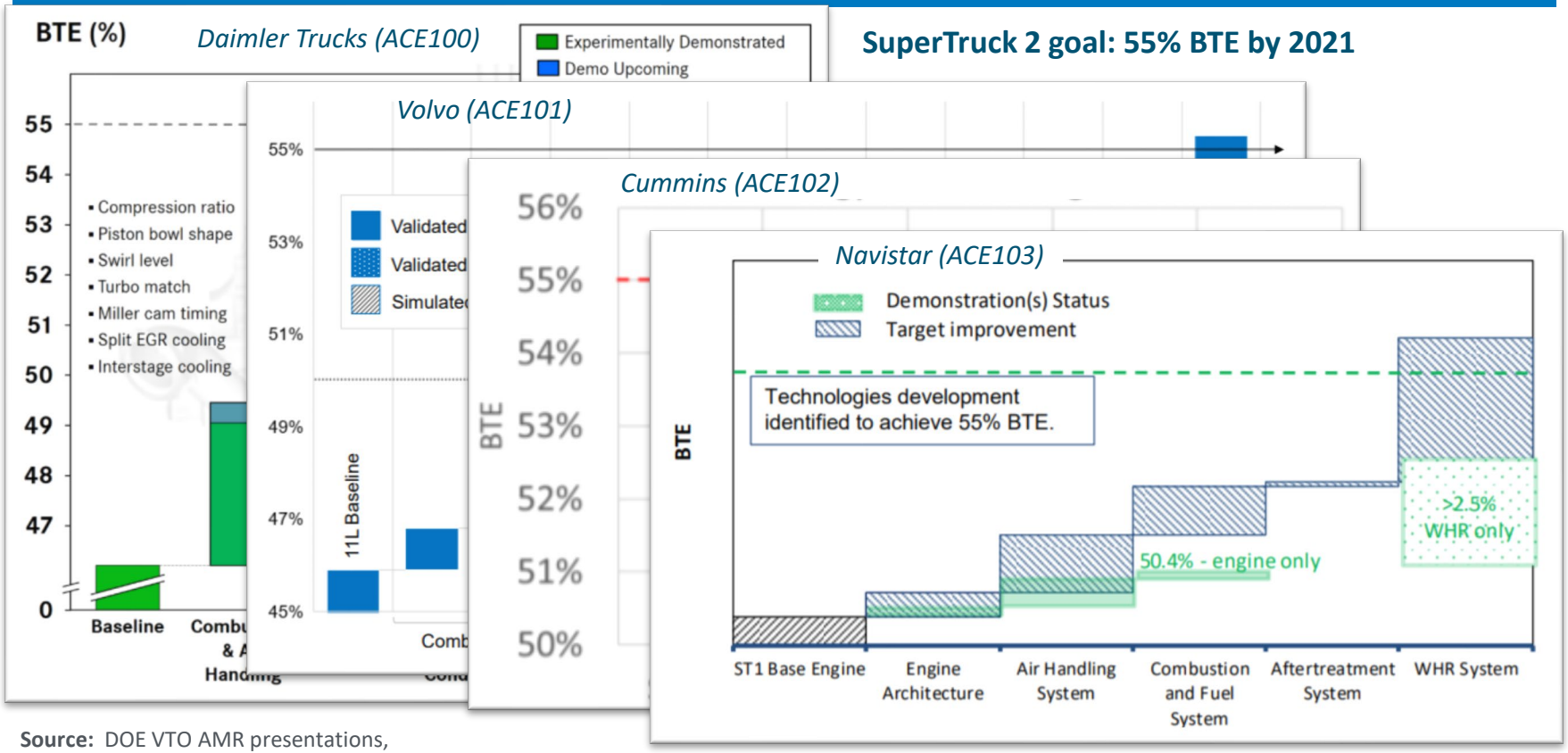
How changing freight patterns effect energy

Freight Demand	Vehicle Fuel Efficiency	Logistics Efficiency	Road System Efficiency
• Origin / destination	☑Size Class	☑Vehicle Load Factor	• Network Accessibility
• Commodity	☑Powertrain and vehicle technology	☑Empty Miles	• Structural Condition
☑Timing ✓	• Payload capacity	☑Routing	☑Congestion
• Mode choice			

Emerging Technologies and Freight Truck Efficiency



Research is advancing diesel internal combustion engines toward 57% brake thermal efficiency



Source: DOE VTO AMR presentations, https://www.energy.gov/eere/vehicles/annual-merit-review-presentations

Emerging Technologies 1: Electrified Powertrains

SMART scenario 1

Using BEVs to transport all freight shipped by trucks under 500 miles in 2050

- 48% of truck ton-miles
- 17-24% of class 7&8 truck stock
- 0.6 quads saved

Cost effective?

SMART scenario 2

Portfolio of electrified technologies meeting VTO goals, deployed in class 7&8, by 2050

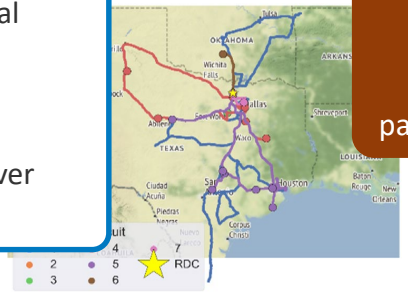
Based on cost-effectiveness and range limitations but assuming adequate fuel infrastructure:

- 83% of tractor sales, 72% of in-use stock electrified
- Little BEV adoption in tractors
- 30% of single unit truck sales, mostly PHEV

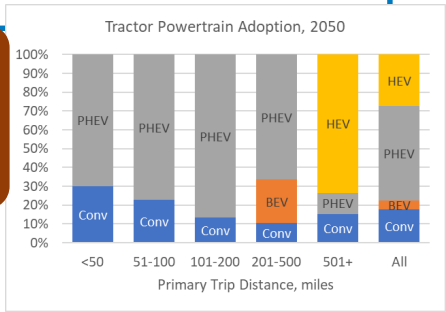
SMART AFI Analysis

For a fleet of trucks operating from a regional distribution center (RDC)

- 84% of trips < 300 mi
- 500-mi range BEV + 350 kW charging
- Charging at the RDC and *all stops* needed to cover 94% of trips



All analyses assume no reduction in payload capacity



Feasibility depends on trip distance, availability and power of charging infrastructure.
Energy savings and payback depend on duty cycle and annual usage.
Regional delivery not as simple or short as expected.

Emerging Technologies 2: Hydrogen Fuel Cells

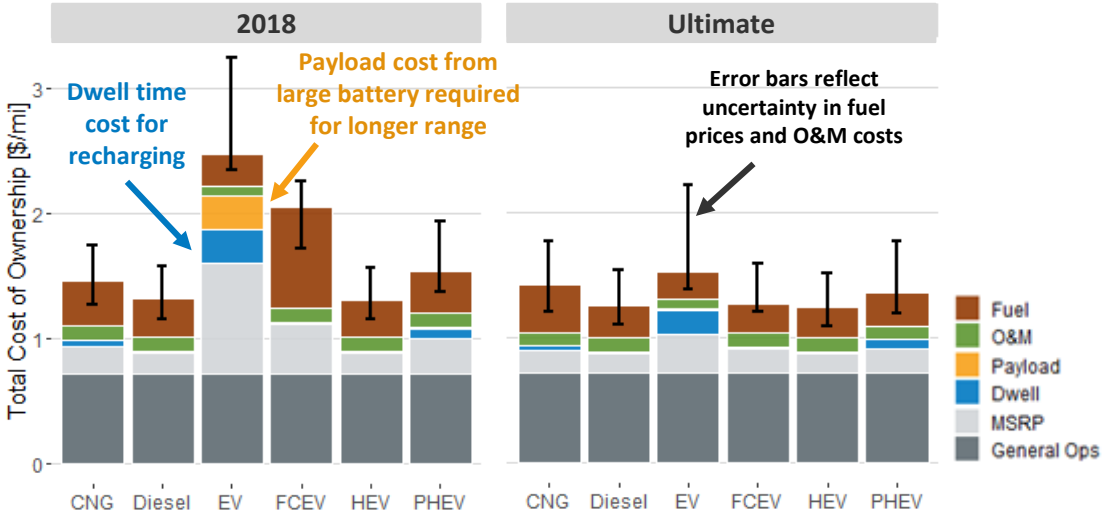
Class 8 Long Haul (750 mile range)

FASTSim — Vehicle Powertrain Cost Modeling

SERA — Total Cost of Ownership Modeling

TCO Scenario Assumptions

- Mid-Atlantic Region
- 100,000 mi/yr, 10 year life
- High Payload Cost, High Dwell Cost
- Fuel, O&M Costs = Mid
- Discount Rate = 7%

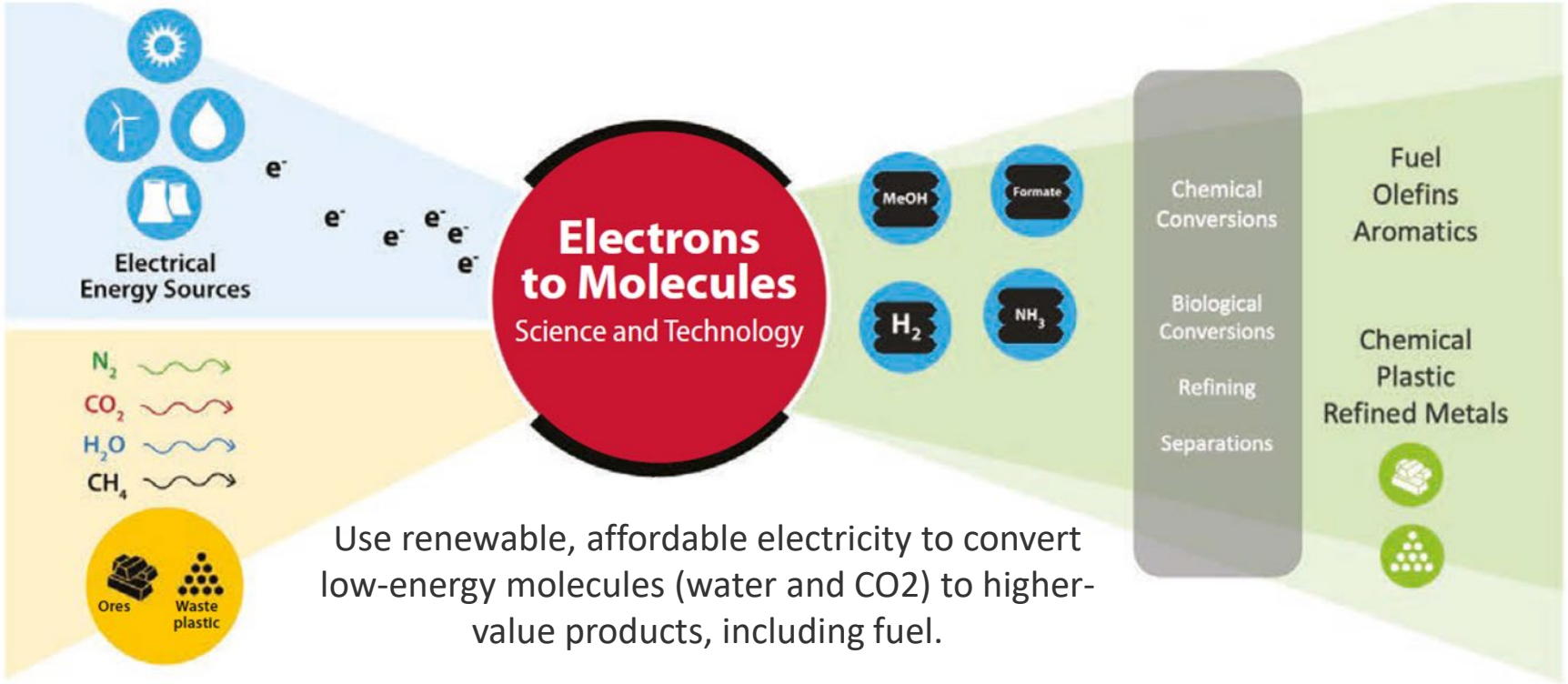


Note: Diesel price range from ~$2.50/gal (2018) to ~$3.50/gal (2050) based on AEO Outlook Middle Atlantic region

H_2 Fuel Cell Powertrains TCO Insights:

- **Hydrogen fuel price** is a key factor to all trucks TCO and M/HD refueling cost reduction should be a key focus area for R&D
- **Lost payload capacity** for Class 8 long haul FCEVs is not critical to the TCO due to the 2,000lb exemption for alternative powertrain trucks[1]
- ***Class 8 long haul FCEVs are the lowest cost ZEV*** *if DOE targets are met (regardless of dwell and payload costs)*
- **Class 8 short haul FCEVs are the lowest cost ZEV** if dwell time costs are incurred and 2025 DOE targets are achieved
- FCEV dwell times for Class 4 parcel delivery trucks are estimated **to be equal to diesel trucks** because of the small hydrogen fuel tank size (less than 8 kg to meet the ~120 mile range required)

Emerging Technologies 3: Carbon Neutral Liquid Fuels



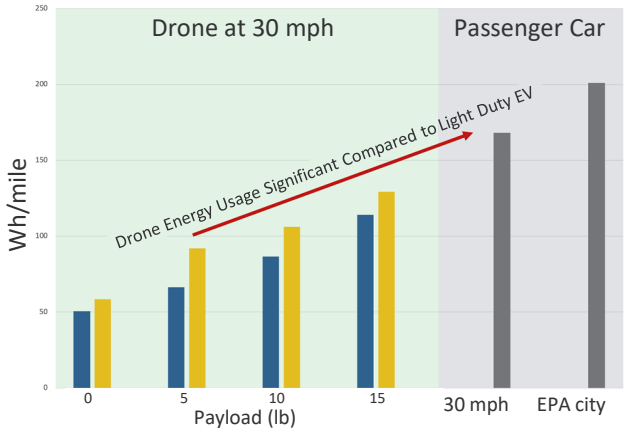
Use renewable, affordable electricity to convert low-energy molecules (water and CO2) to higher-value products, including fuel.

A possible strategy for transportation applications requiring high energy-density on-board.

Emerging Technologies 4: New modes and business solutions

- Drones, bots, micro-freight (e-bikes)
- Asset sharing (e.g. Amazon Flex)
- Trip distance, shipment weight, and load factors impact applicability and energy use / freight efficiency

Solutions to improve cost, access, congestion, and local emissions may not improve freight energy efficiency (Btu/ton-mile) or life-cycle emissions.



Source: V. Walker, INL for SMART, P20-21764

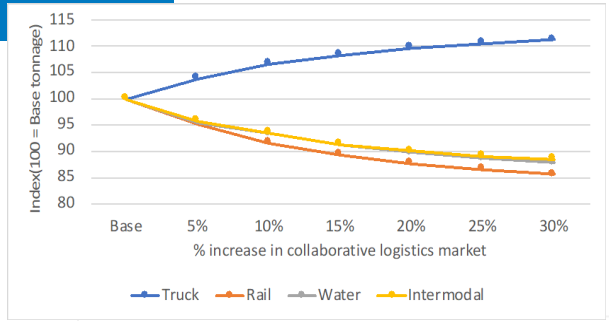
https://workhorse.com/horsefly.html

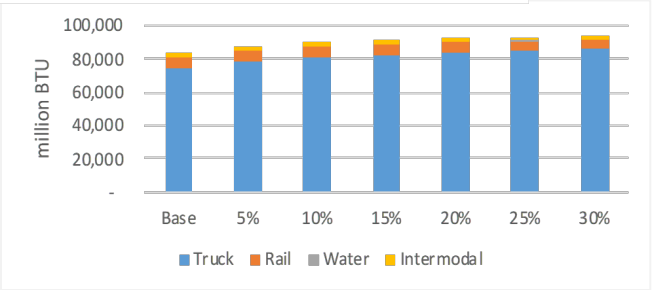
https://nuro.ai/product

UPS

Emerging Technologies 5: Connectivity, telematics, data analytics, automation

- Preventative maintenance
- Route optimization
- Load pooling / asset utilization
- Automation (ACC, CACC, platooning, full)
  - Crash rate reduction
  - Eco-driving and traffic smoothing
  - Operating cost reduction (driver)
  - Could length of haul increase? (L4-5)
- Feedback to mode choice?





SMART multi-modal energy model demonstrated how improved logistics and reduced costs in trucking could shift freight from rail to truck and increase total energy consumption.

How emerging technologies can impact energy

Freight Demand	Vehicle Fuel Efficiency	Logistics Efficiency	Road System Efficiency
• Origin / destination • Commodity • Timing ☑Mode choice	☑Size Class ☑Powertrain and vehicle technology ☑Payload capacity	☑Vehicle Load Factor ☑Empty Miles ☑Routing	• Network Accessibility? • Structural Condition ☑Congestion

Summary

- Freight trucking patterns are changing
  - Causality is complicated
  - Changes are more about logistics – mode, vehicle, route, schedule, operations – than shipping distance (origin-destination)
  - National freight data does not capture these changes
- Emerging technologies have the potential to reduce truck energy and emissions, but…
- Biggest changes and concerns are in last-mile delivery
  - Not the largest energy portion (total) but it is expensive and possibly biggest bottleneck to on-time delivery
  - Urban congestion, emissions
  - Industry response and technology solutions likely to be tailored to shippers' and urban planners' main concerns (congestion, cost, on-time delivery, curb management, air quality) rather than energy
- In long haul, need to consider possible mode shifts if trucking costs change
- Systems perspective is required to understand change and project sustainability impacts

Thank you

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