

Opportunities and Challenges for Energy and Emission Reduction from Advanced Heavy Duty Vehicles

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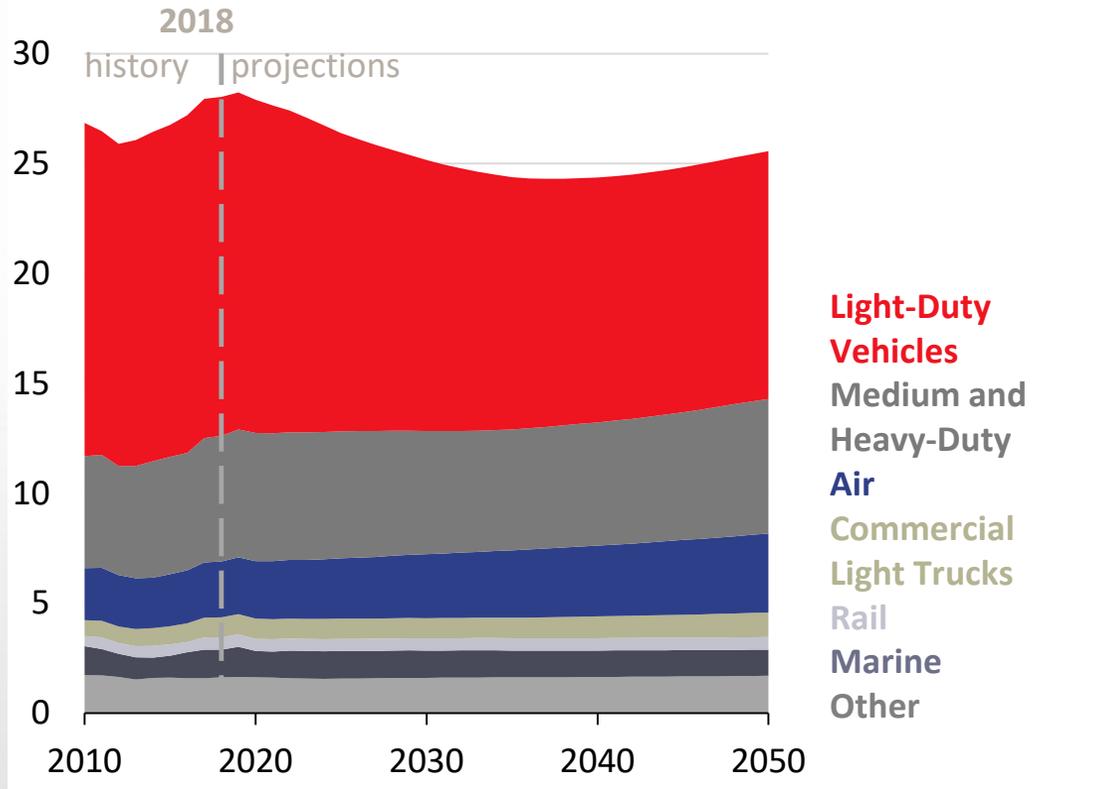
Vocational



>16t



Transportation sector consumption (by type)
(Reference case)
quadrillion British thermal units

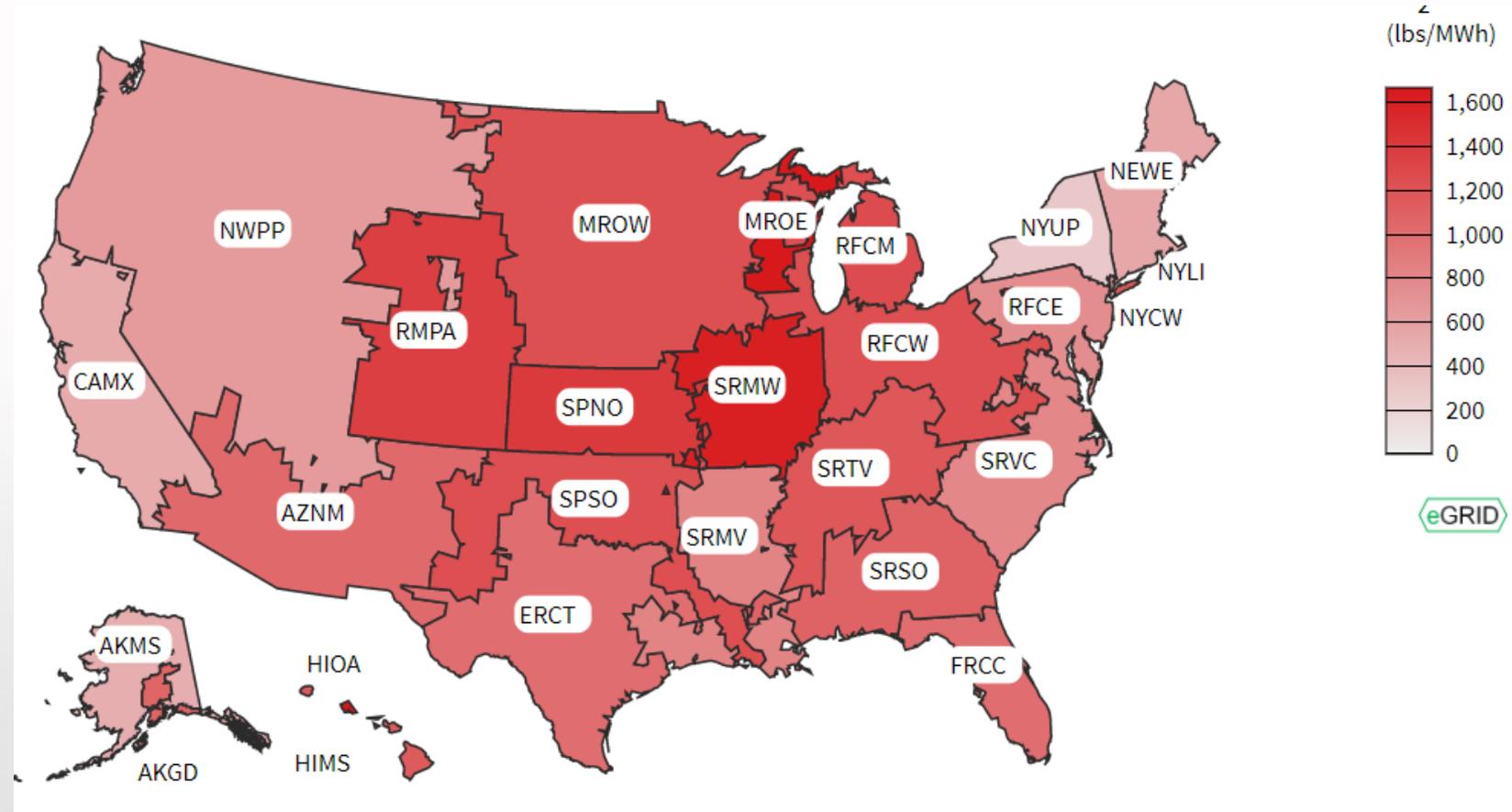


“Annual Energy Outlook 2019”, U.S. Energy Information Administration

- Transportation (Land, Sea, Air) is Responsible for ~ 30% of U.S. Greenhouse Gas Emissions (15% Worldwide)
- Heavy-Duty Trucks Account for Over 20% of Fuel Consumed in the U.S. Transportation Sector
- Approximately 70% of US Freight Tonnage Transported by Trucks
- Truck Vehicle Miles Traveled (VMT) Projected to Grow by Over 50% Between now and 2050

Grid Carbon Intensity – Location Matters!

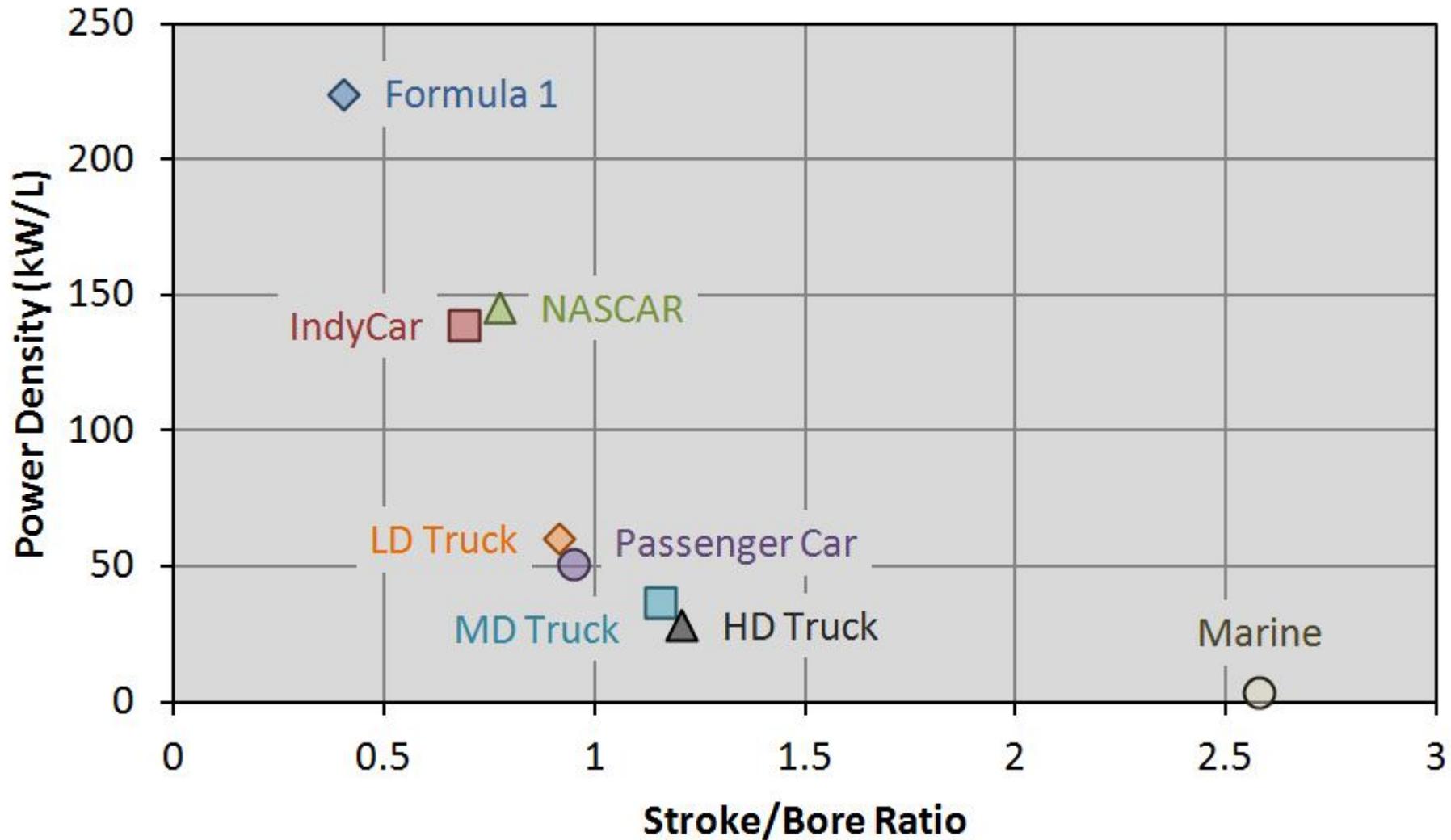
- Where the electricity is generated makes a big difference!
- Above ~800-1200 lbs/MWh (Depending On Assumptions) Diesel Is More Carbon Efficient
- Source: <https://www.epa.gov/energy/power-profiler#/>
- Critical question – What “greens” Faster, The Fuel (Low Carbon) Or The Grid?



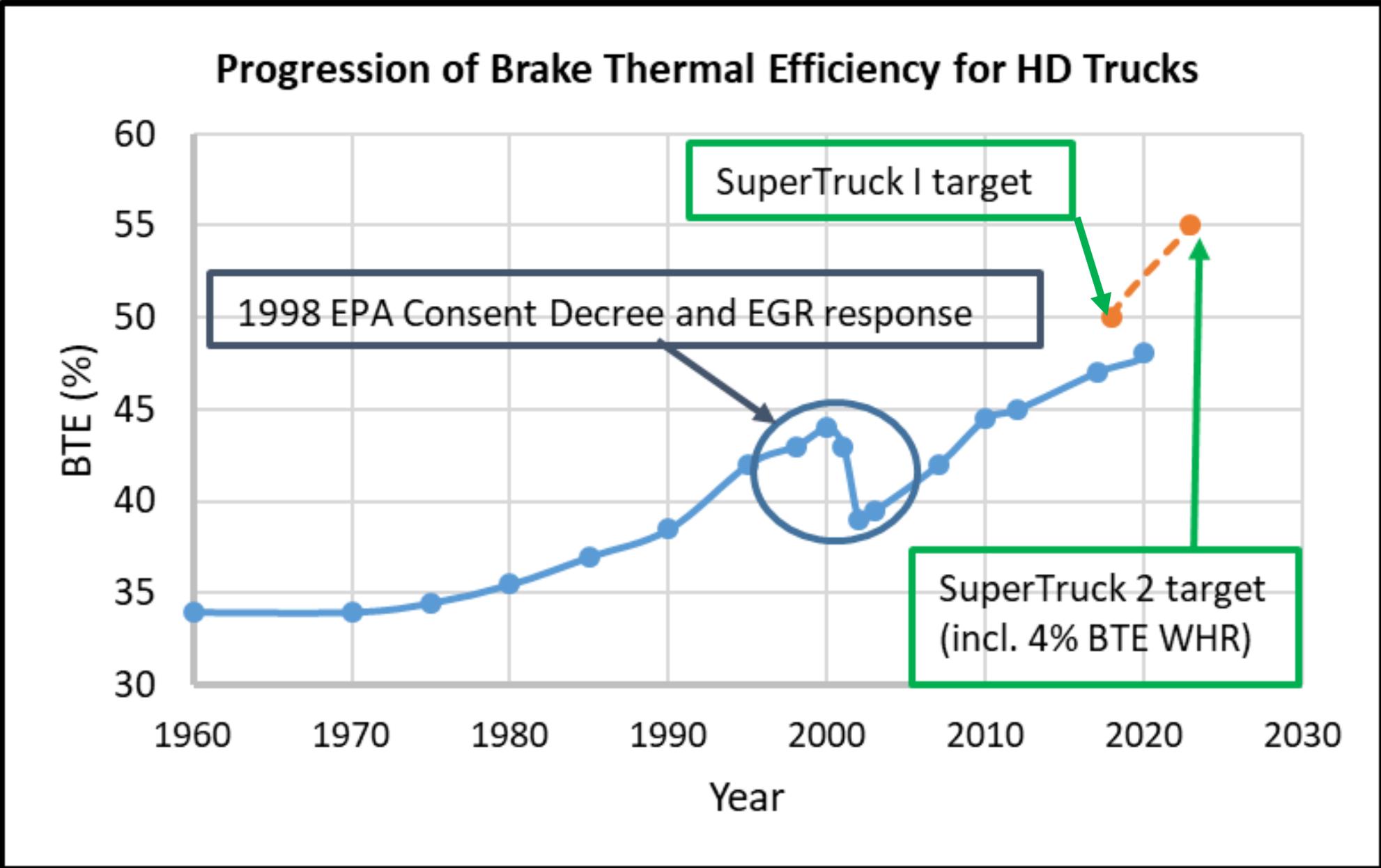
Freight Efficiency Comparison To Fuel Economy & BTE **PACCAR POWERTRAIN**



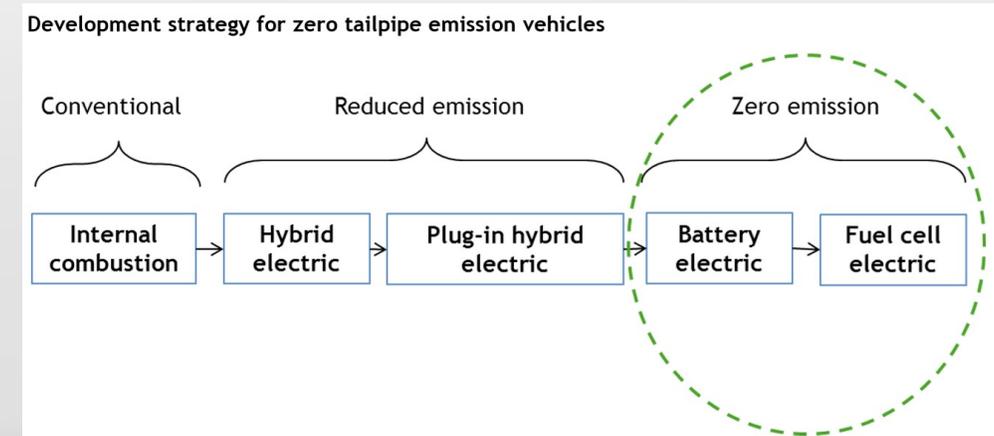
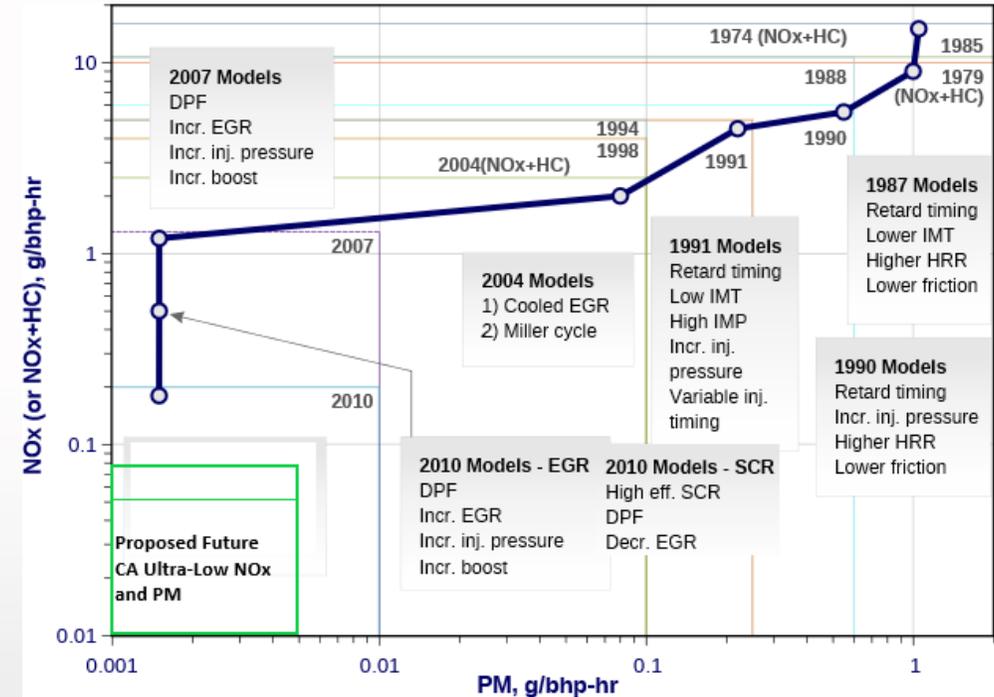
	Automobile	Peterbilt Supertruck	CSX Freight Train
Fuel Economy	37.0 mpg	10.7 mpg	0.16 mpg
Freight Carried	0.4 ton	16.6 tons	3000 tons
BTE	18-35%	36-45%	40-45+%
Power/weight	100+ hp/ton	15 hp/ton	<1 hp/ton
Freight Efficiency	14.8 ton-mile/gal.	178 ton-mile/gal.	480 ton-mile/gal.



Example: ST-2 pursues 55% BTE (Marine Engine). If marine engine geometry were used, the truck engine would be roughly 120 L displacement running at 100 RPM.



- Two Primary Issues
 - GHG (WTW Assessment Needed)
 - Air Quality (More Localized But Also Important)
- Top Graph - Emissions Regs For HD Trucks
 - Log-Log Plot; Each Major Line Is 90% Reduction
- Regulations May Also Dictate Technology Choices
 - Vehicle Application & Solution Need To Fit Together
 - Technology (Which Tech For Which Market?)
 - Economic (Does Tech Cost Fit The Market?)



Electricity



Green Fuels

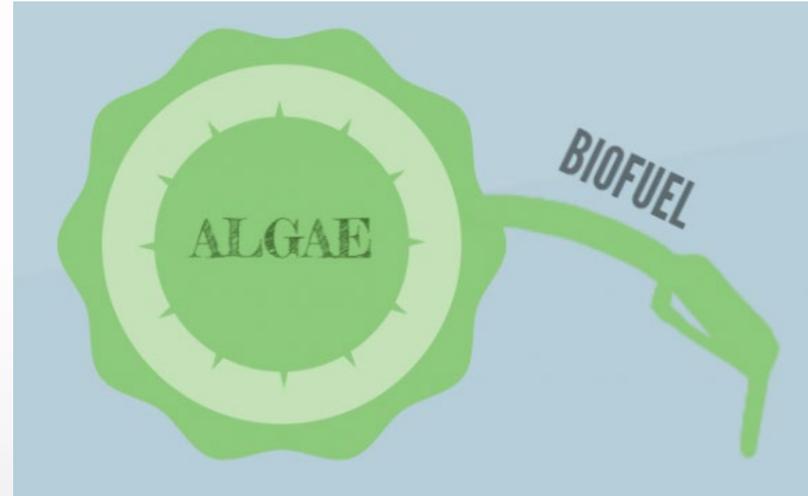


Image from: <https://www.energy.gov/eere/bioenergy/bioenergizeme-infographic-challenge-algae-biofuel-0>

Hydrogen Gas



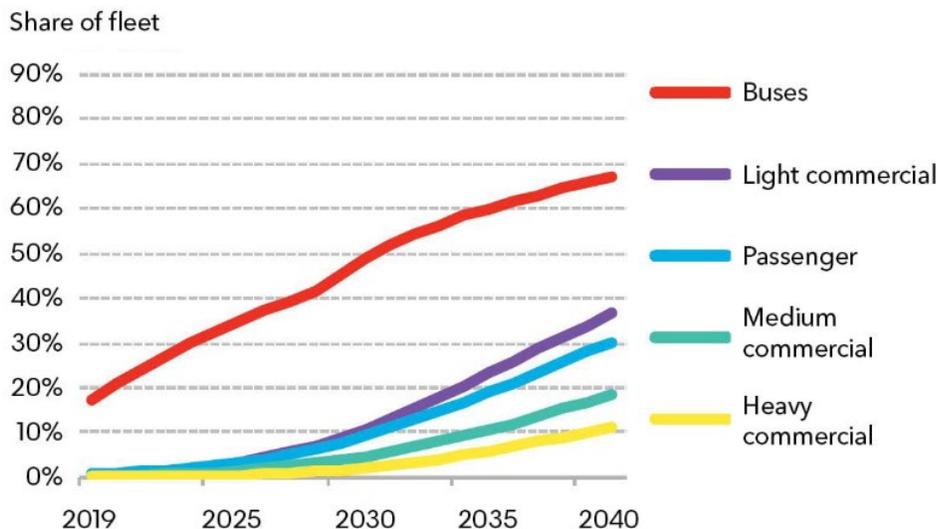
We Need To Minimize:

CO₂ From Fuel Production + CO₂ From Vehicle Lifecycle + CO₂ From Tailpipe

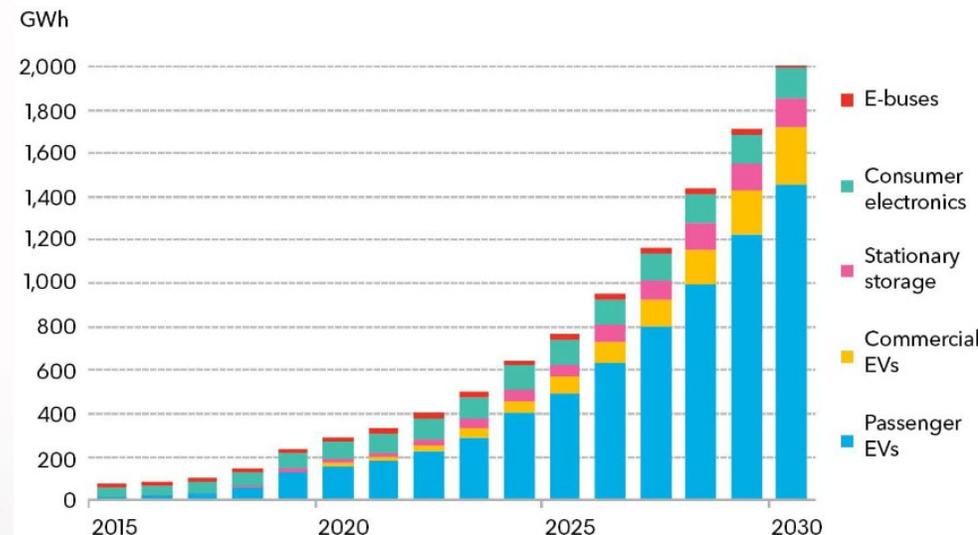
While Maintaining Acceptable:

Productivity, Operating Cost, Infrastructure Cost

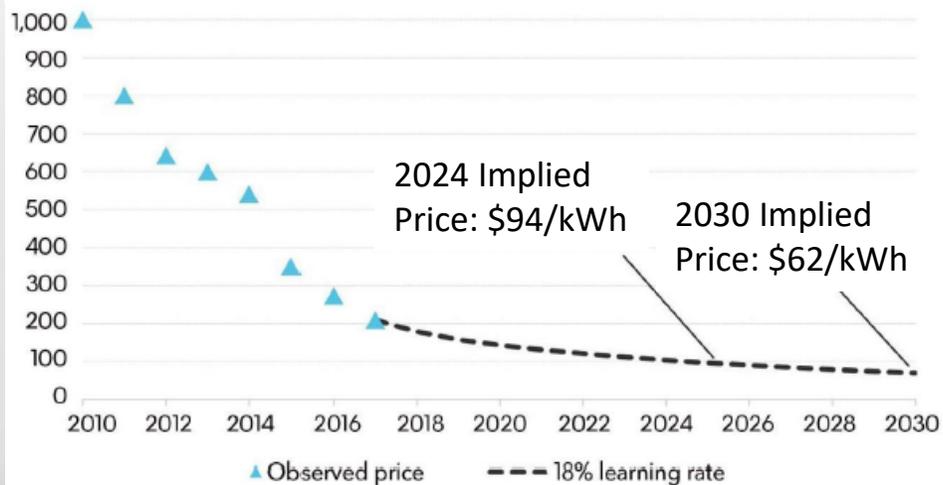
EV share of global vehicle fleet by segment



Annual lithium-ion battery demand



Li-Ion Battery Price (\$/kWh, 2018 Real)

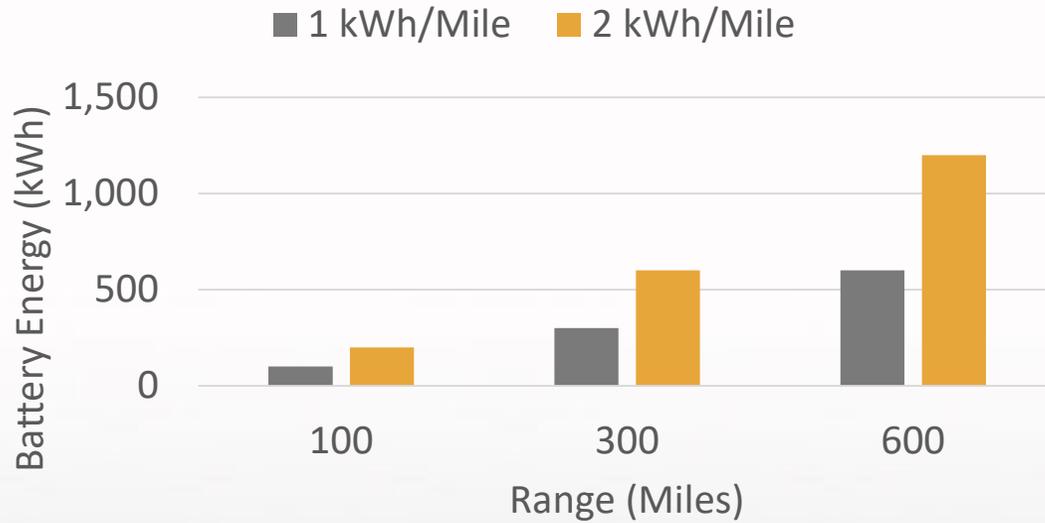


Source: Bloomberg NEF

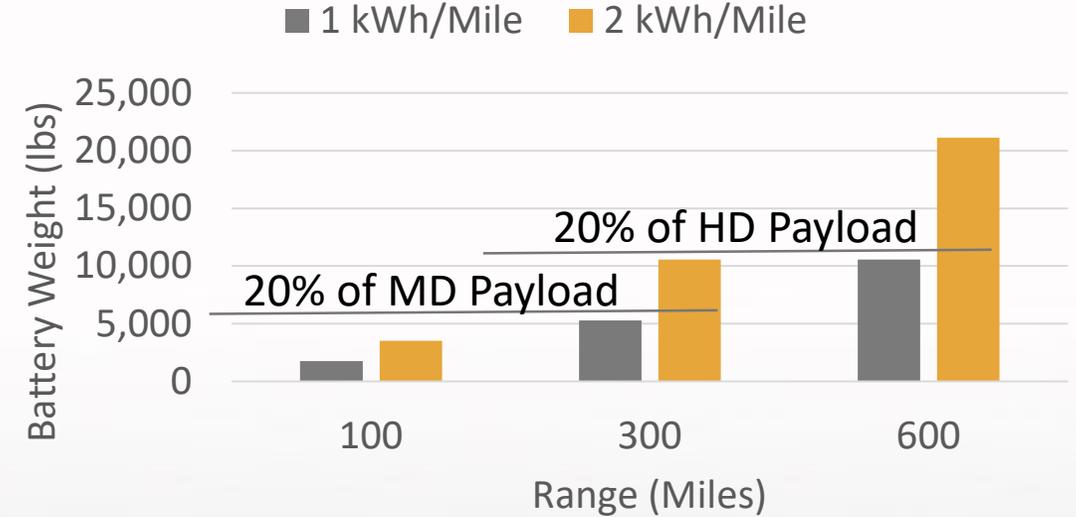
- EV Demand on the Rise: Light- and Medium-Duty Likely First Adopters
- Demand of Li-Ion Batteries Increasing Rapidly
- Batteries More Powerful and Less Expensive

Battery Considerations

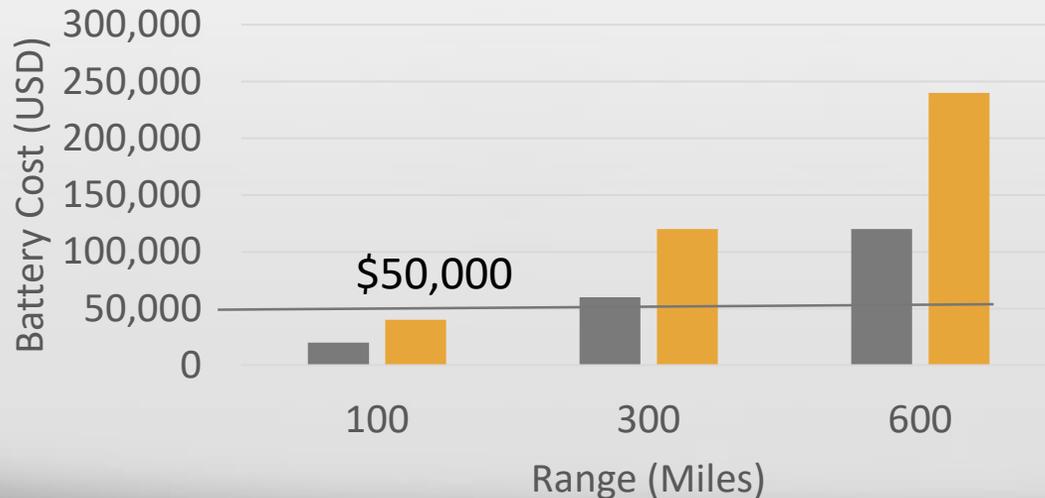
Battery Capacity



Battery Weight



Battery Cost



- Assumptions:
 - 16 lbs/kWh
 - \$200/kWh
- Conclusion:
 - BEV CV Not Feasible > 300 Miles



DAF XF/CF
Parallel Hybrid
Electric Range 20 Miles



DAF CF Electric
Electric Range 75 Miles



Kenworth / Toyota H2 FC
Range 300 Miles



Peterbilt Electric Refuse
Electric Range 80 Miles



Peterbilt Electric Port
Electric Range 150 Miles



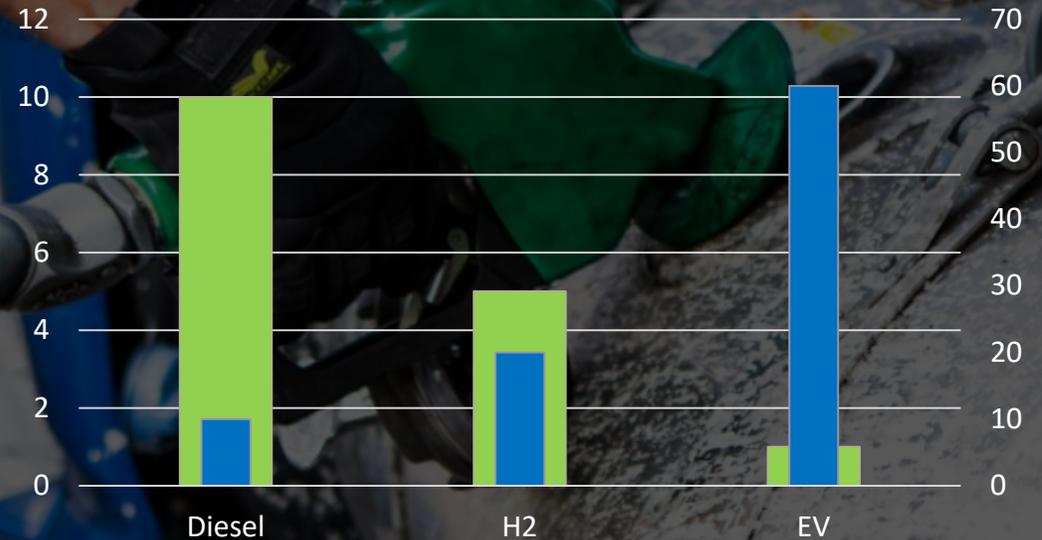
Kenworth Hydrogen Drayage
Electric Range 150 Miles

Charging Consideration

- Drivers Cost Fleets About \$40/h
 - 5 Minutes/Day Costs About \$1000/year
- Convenience Matters
 - EVs
 - Fast charging: Limited Infrastructure
 - Slow charging: Installed at Fleet Location
 - Monitoring not Needed
 - Can Disrupt 2 or 3 Shift Operation
 - Affected by Power Outages/Disasters
 - H2
 - Limited Infrastructure
 - Monitoring Required
 - Diesel
 - Ubiquitous
 - Monitoring Required

Fill Rate (MW)

Fill Time (min)



- Regulatory And Market Pressure Are Changing The Freight Transport Business
- Advanced Technology Is Needed To Meet These Targets
 - WTW Analysis Is Critical To Insure We Don't Follow The Wrong Path!
 - TTW Leads To Deceptive Conclusions That Will Not Enable Achieving Goals
 - Technology Needs To Fit The Application & Meet The Market Constraints
 - TCO & Uptime Are The Most Important Factors To Our Customers
 - Even More Than Fuel Economy; 1 Day of Downtime/Month is 5% FE!
 - Freight Efficiency Is a Better Metric Than MPG
- The HD Truck Industry Is Investigating All Of These Technologies And More
 - No One Can Afford To Be Left Behind
 - Freight Transport Is Changing & We Will Change With It
- Solutions That Seem Like A Slam-Dunk Aren't Always So