HEC Hydrogen Sessions

Hydrogen Fuel Cell Electric Trucks and Fueling Infrastructure

May 7, 2021, 12:00 noon

Brad Bradshaw
President, Velerity
President, Hydrogen Energy Center
brad@velerity.com

Hydrogen Energy Center

HEC is a professional association focused on accelerating the hydrogen as an enabling solution for renewable energy

HEC provides public forums, conducts research and implements projects focused on accelerating the clean energy future

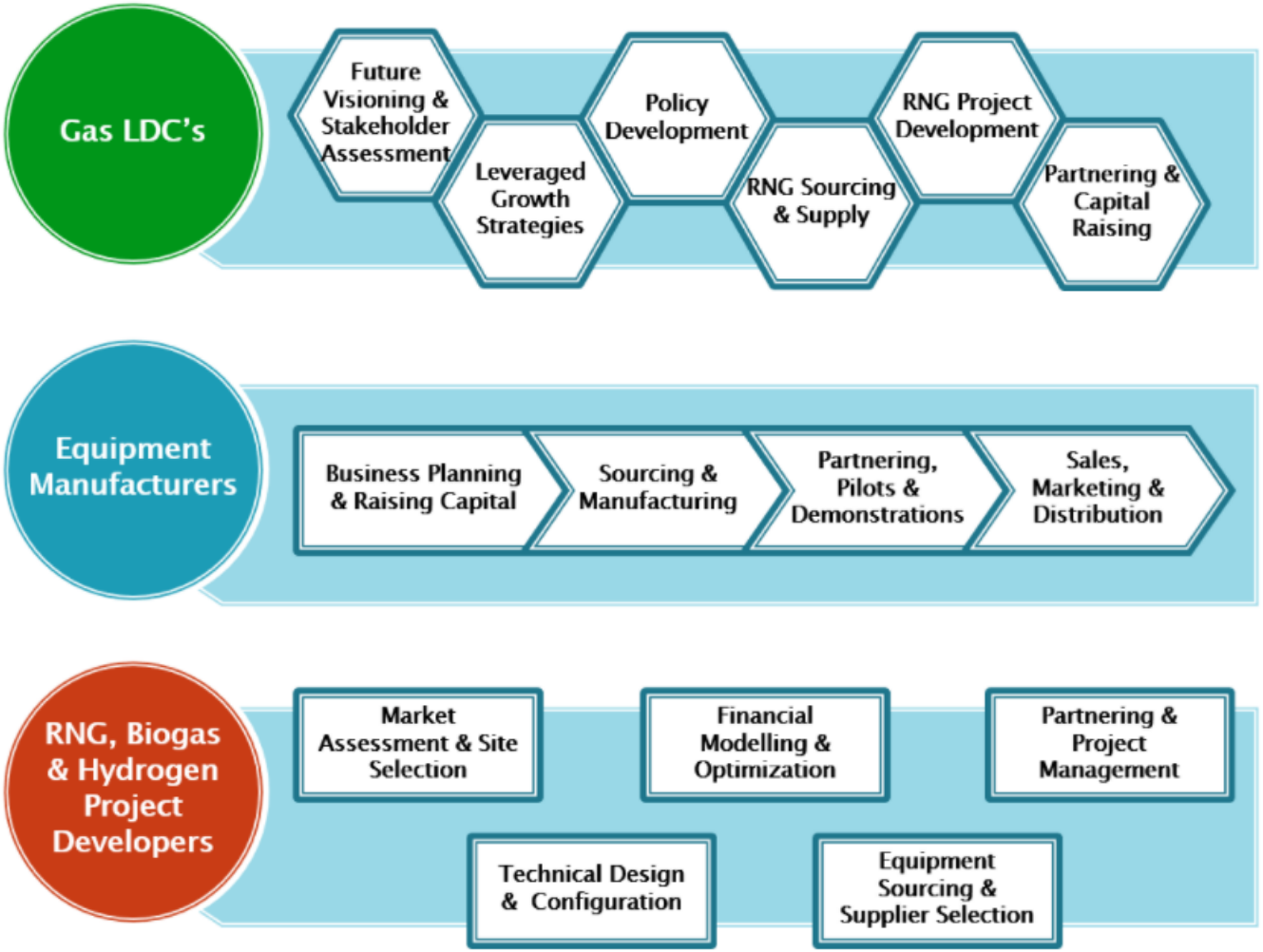
Consider supporting this important effort by becoming a member:

- Influence the course of renewable hydrogen energy technology and policy.
- Be a part of projects that really build hydrogen solutions.
- Have full access to white papers, technical reports, and meeting minutes from our projects and from other organizations.
- Immerse yourself in the hydrogen "goings-on" by connecting with developments & networking with people who are collectively driving the hydrogen "bus".

Upcoming Hydrogen Sessions

- May 14, 2021 — 100% Hydrogen Pipelines
- May 21, 2021 — Power Production with Hydrogen
- May 28, 2021 — Building a Global Trade in Hydrogen
- June 4, 2021 — Electrolysis and Water Splitting
- June 11, 2021 — Hydrogen Production with Carbon Separation
- June 18, 2021 — Wind to Hydrogen

Velerity Services

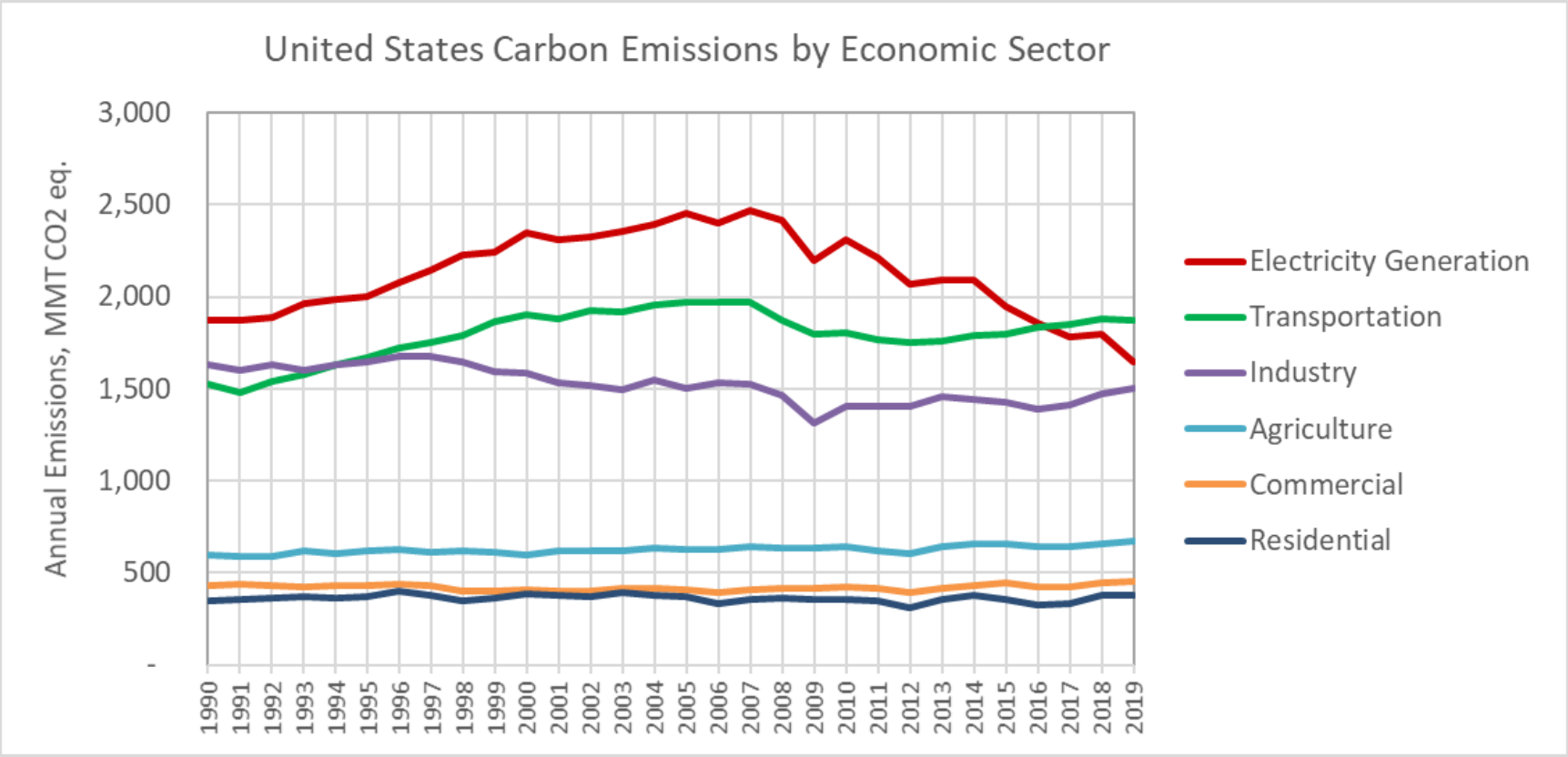


Velerity – Illustrative Clients

The move to zero carbon trucking is underway and complex

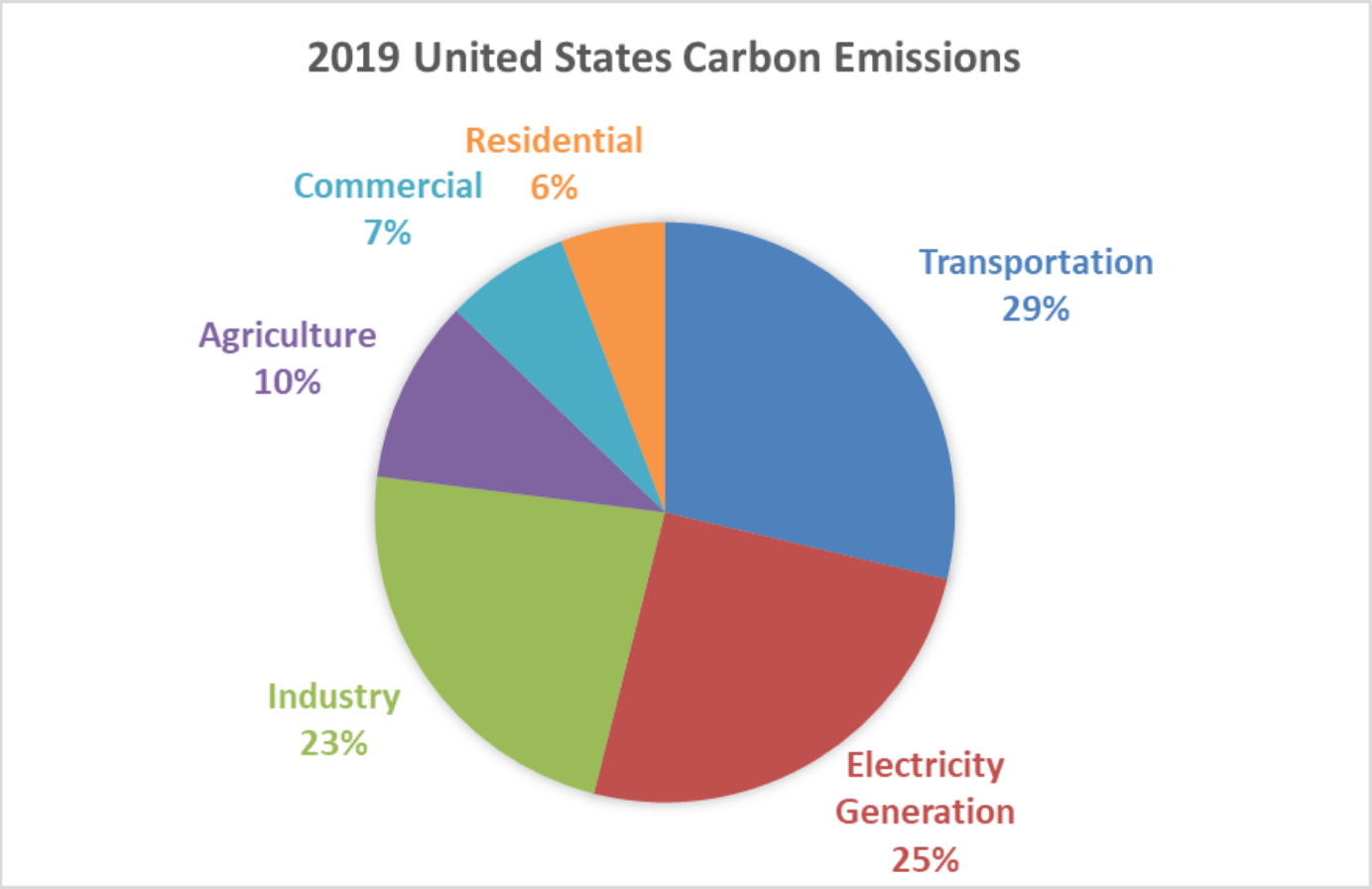
- Carbon initiatives turning to transportation and building heat energy
- Transportation emissions have been increasing
- California introduced zero emission truck requirements beginning in 2024
- Manufacturers need to develop zero emissions trucks
  - Key question: battery electric or fuel cell electric?
- Many considerations and trade-offs to consider:
  - Weight
  - Fuel cost
  - Fuel availability
  - Refueling time
  - Range
  - Safety
  - Truck cost

Electric sector emissions have gone down while transportation emission have increased in recent years



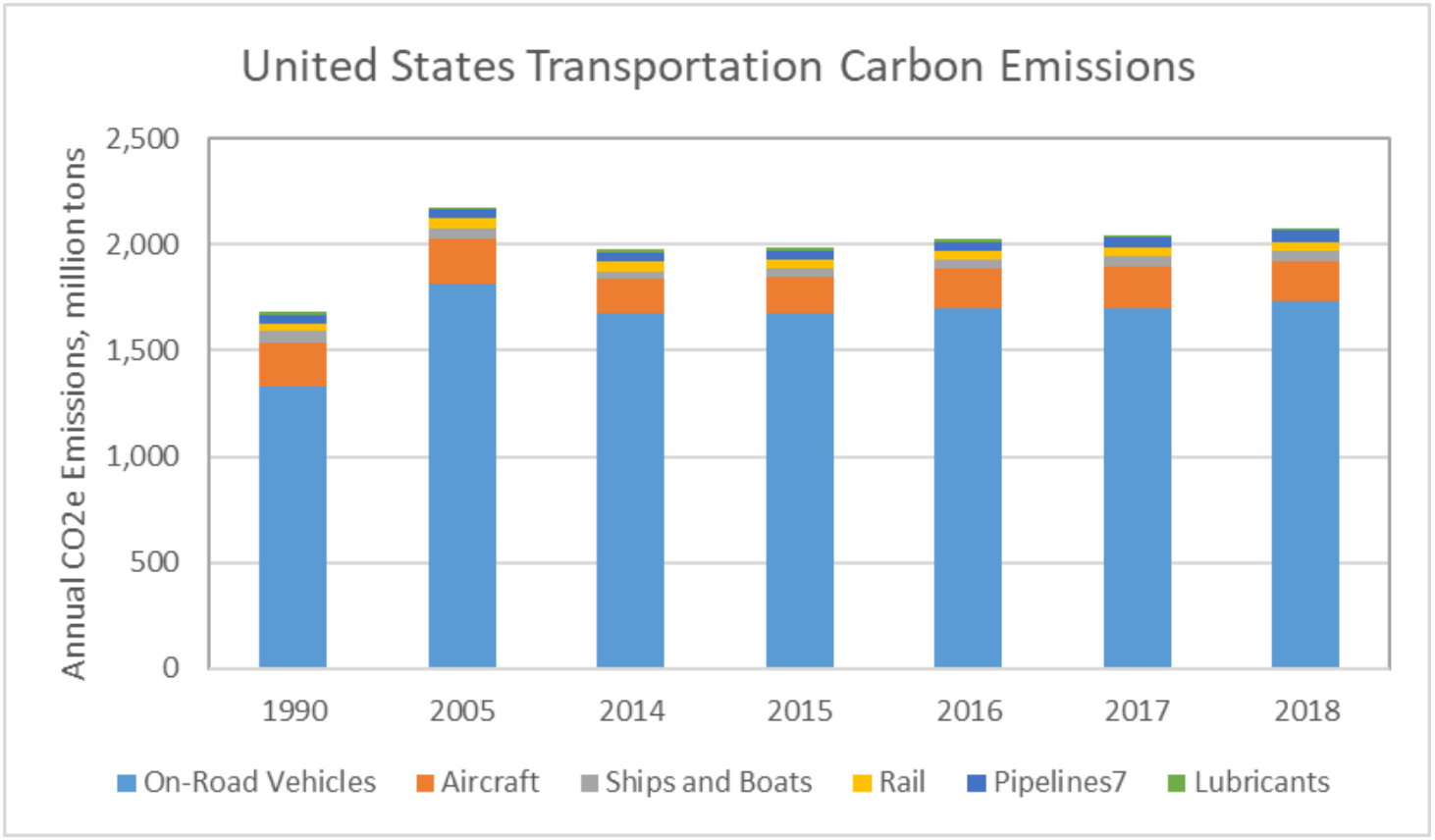
Source: Environmental Protection Agency, U.S. Greenhouse Gas Inventory Data Explorer (cfpub.epa.gov/ghgdata/inventoryexplorer/index.html)

Transportation is now the dominant source of carbon emissions in the United States



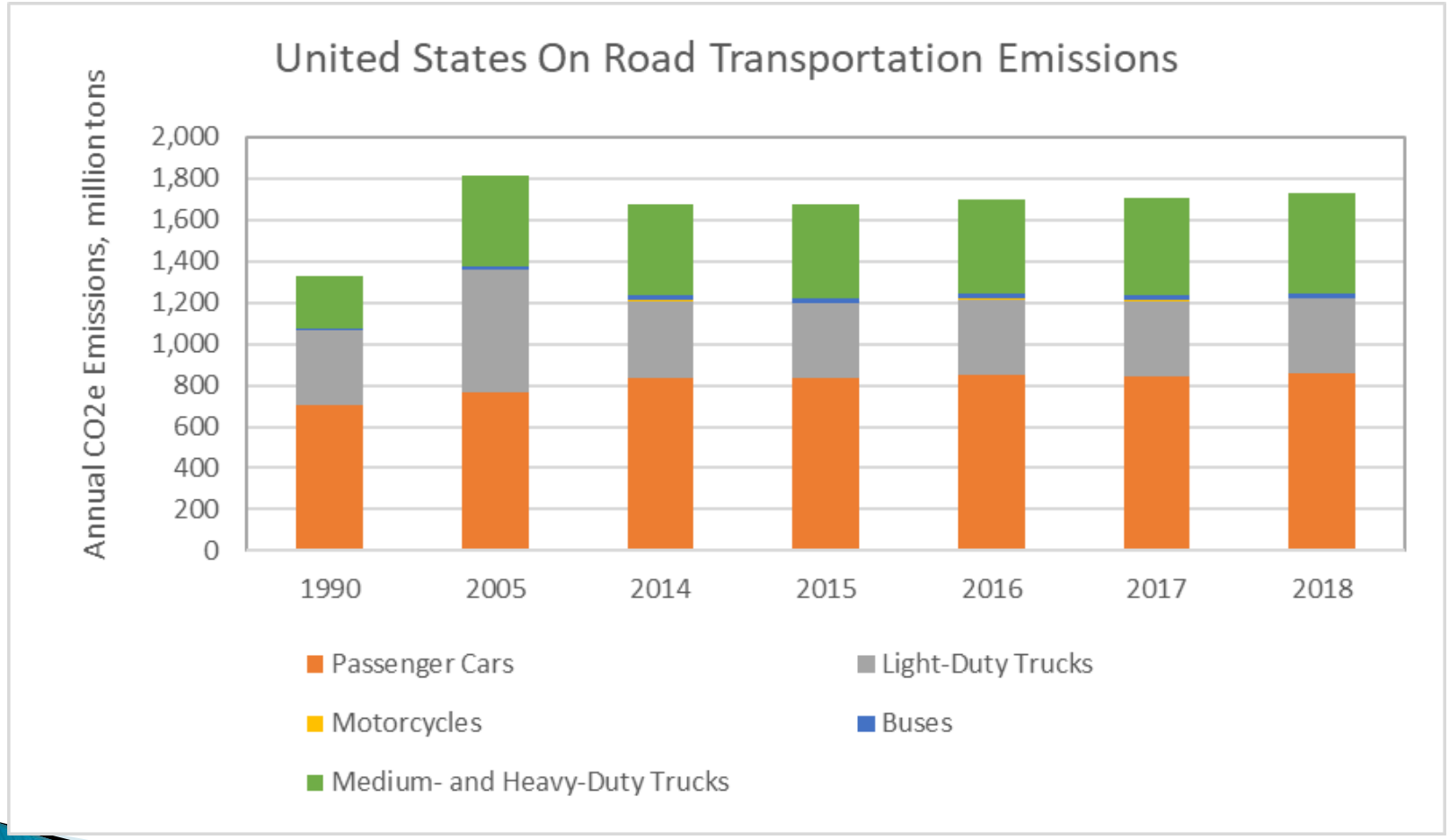
Source: Environmental Protection Agency, U.S. Greenhouse Gas Inventory Data Explorer (cfpub.epa.gov/ghgdata/inventoryexplorer/index.html)

Transportation emissions are dominated by on-road vehicles



Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–2018 (EPA 2020)

Within on-road vehicles, one half of emissions are light, medium and heavy duty trucks



Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–2018 (EPA 2020)

California is the key driver for truckers to begin integrating zero carbon trucks into their fleets

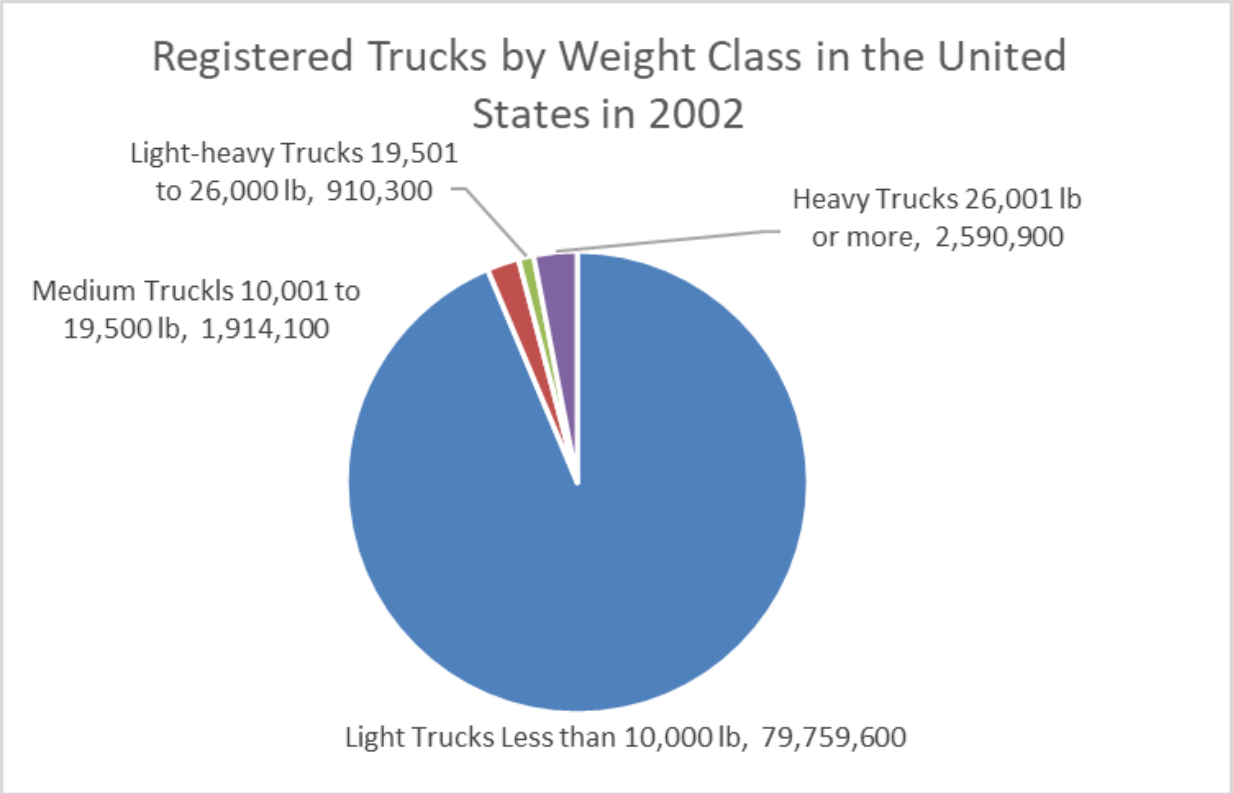
- In June, California proposed its Advanced Clean Truck (ACT) standard. The ACT standard requires incrementally higher adoption rates of on-road zero-emission vehicles from 2024 through 2040, in order to achieve carbon neutrality.
- Beginning in 2024, 3% of Class 2 and 3, 7% of Class 4 through 8 trucks, and 3% of Class 7 and 8 tractors purchased in California must be ZEVs. By 2030, half of Classes 4-6 and 30% of Classes 7 and 8 sales must be ZEVs. By 2045, all new vehicles sold in the state would require they be ZEVs.
- In August, CARB adopted a new ruling to lower NOx emissions for on-highway vehicles. Current CARB NOx limits are 0.2 grams per brake horsepower-hour (g/bhp-hr).
- The incremental reductions for the California state ruling plan to require a further 75% reduction in 2024 to a limit of 0.05 g/bhp-hr and another 90% reduction by 2027 to 0.02 g/bhp-hr.

Source: https://www.fleetowner.com/running-green/emissions/article/21146100/meeting-carb-emissions-regulations-will-require-more-fleet-involvement

There are many types of trucks on the road, so it helps to have some defintions

Table 1: Vehicle weight classes and categories			
Gross Vehicle Weight Rating (lbs)	Federal Highway Administration		US Census Bureau
	Vehicle Class	GVWR Category	VIUS Classes
<6,000	Class 1: <6,000 lbs	Light Duty <10,000 lbs	Light Duty <10,000 lbs
10,000	Class 2: <6,001–10,000 lbs		
14,000	Class 3: <10,001–14,000 lbs	Medium Duty 10,001–26,000 lbs	Medium Duty 10,001–19,500 lbs
16,000	Class 4: <14,001–16,000 lbs		
19,500	Class 5: <16,001–19,500 lbs		
26,000	Class 6: <19,501–26,000 lbs		Light Heavy Duty 19,001–26,000 lbs
33,000	Class 7: <26,001–33,000 lbs	Heavy Duty >26,001 lbs	Heavy Duty >26,001 lbs
>33,000	Class 8: >33,001 lbs		
Source	Alternative Fuels Data Center www.afdc.energy.gov/data/10380		

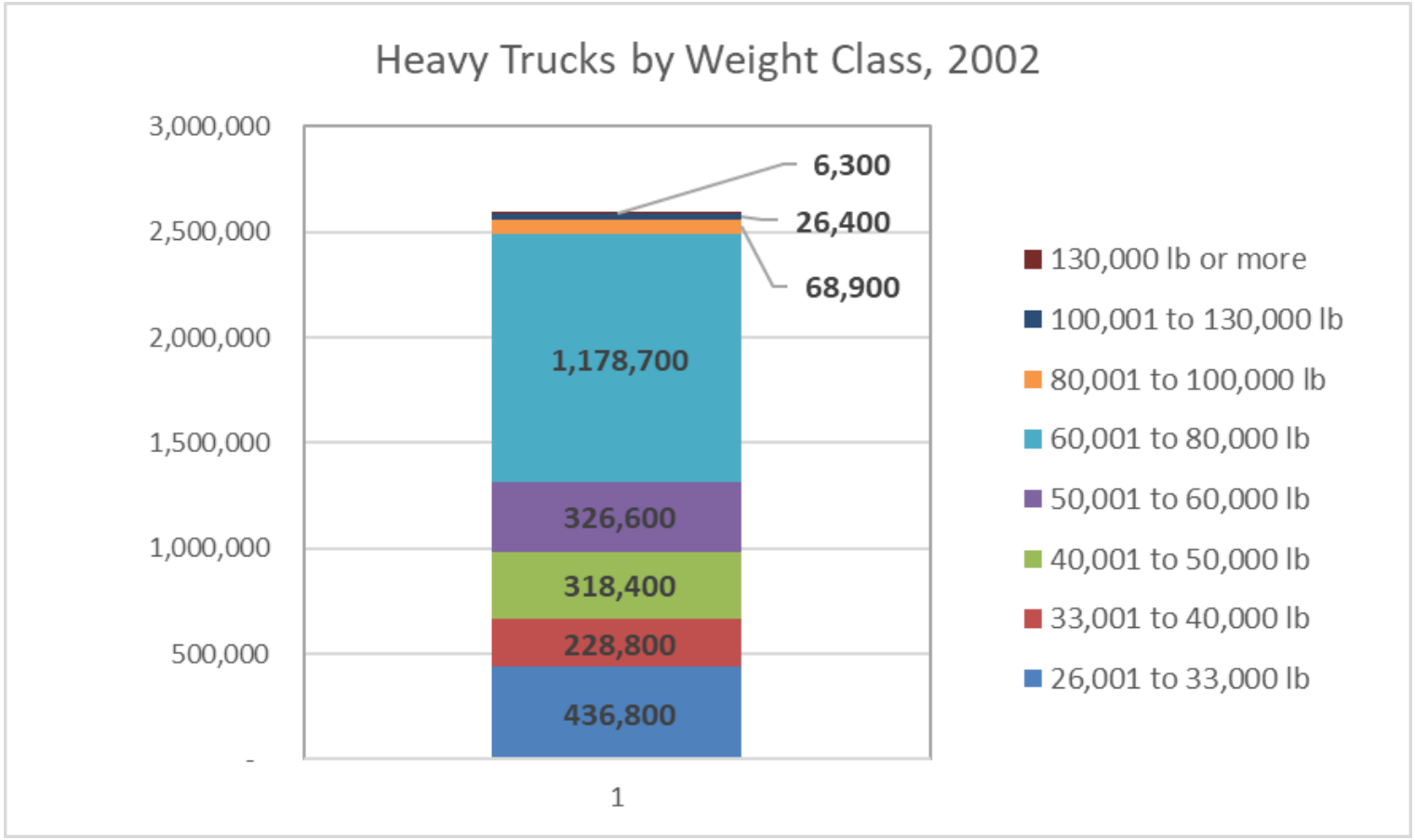
Number of trucks by weight class



1992, 1997: U.S. Census Bureau, 1997 Economic Census: Vehicle Inventory and Use Survey: United States, EC97TV-US (Washington, DC: 1999).

2002: U.S. Census Bureau, 2002 Economic Census: Vehicle Inventory and Use Survey: United States, EC02TV-US (Washington, DC: 2004).

Number of heavy trucks in the United States



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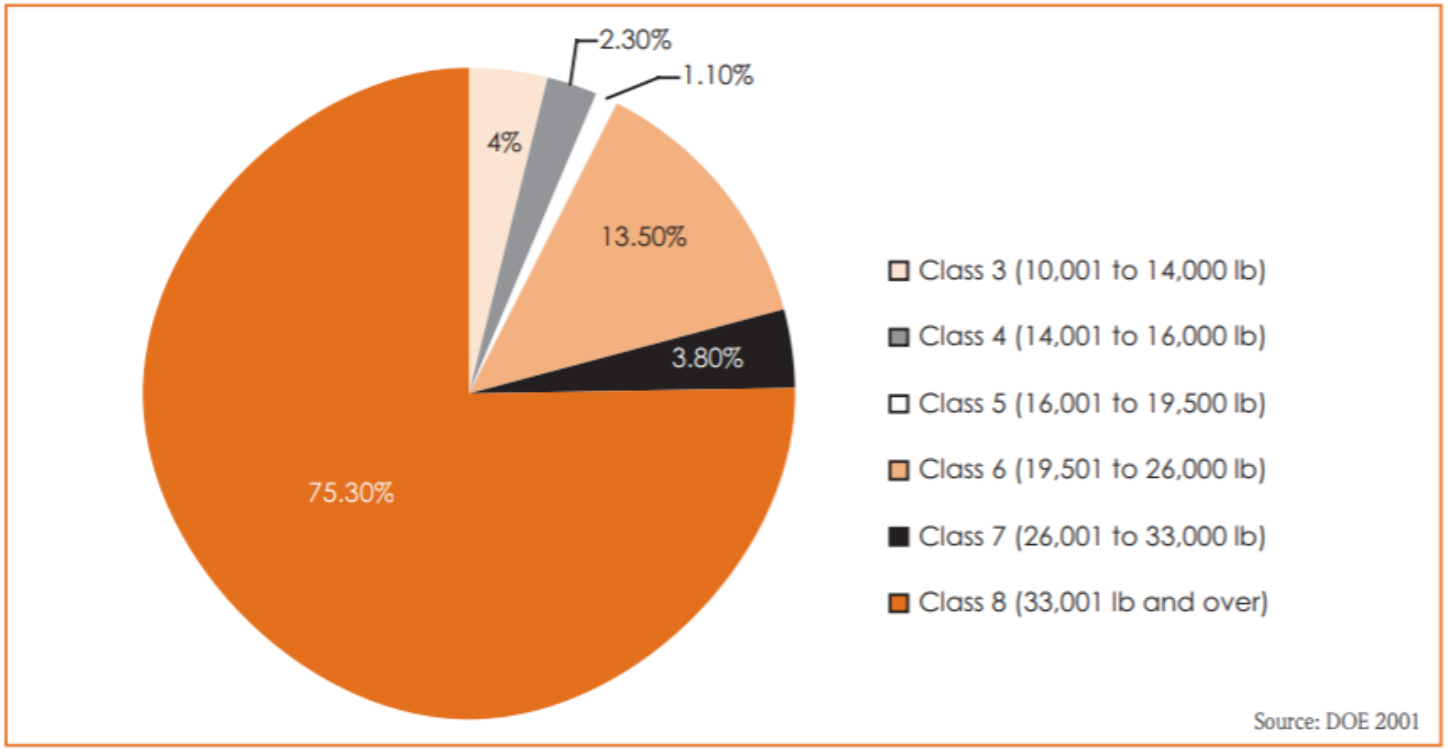
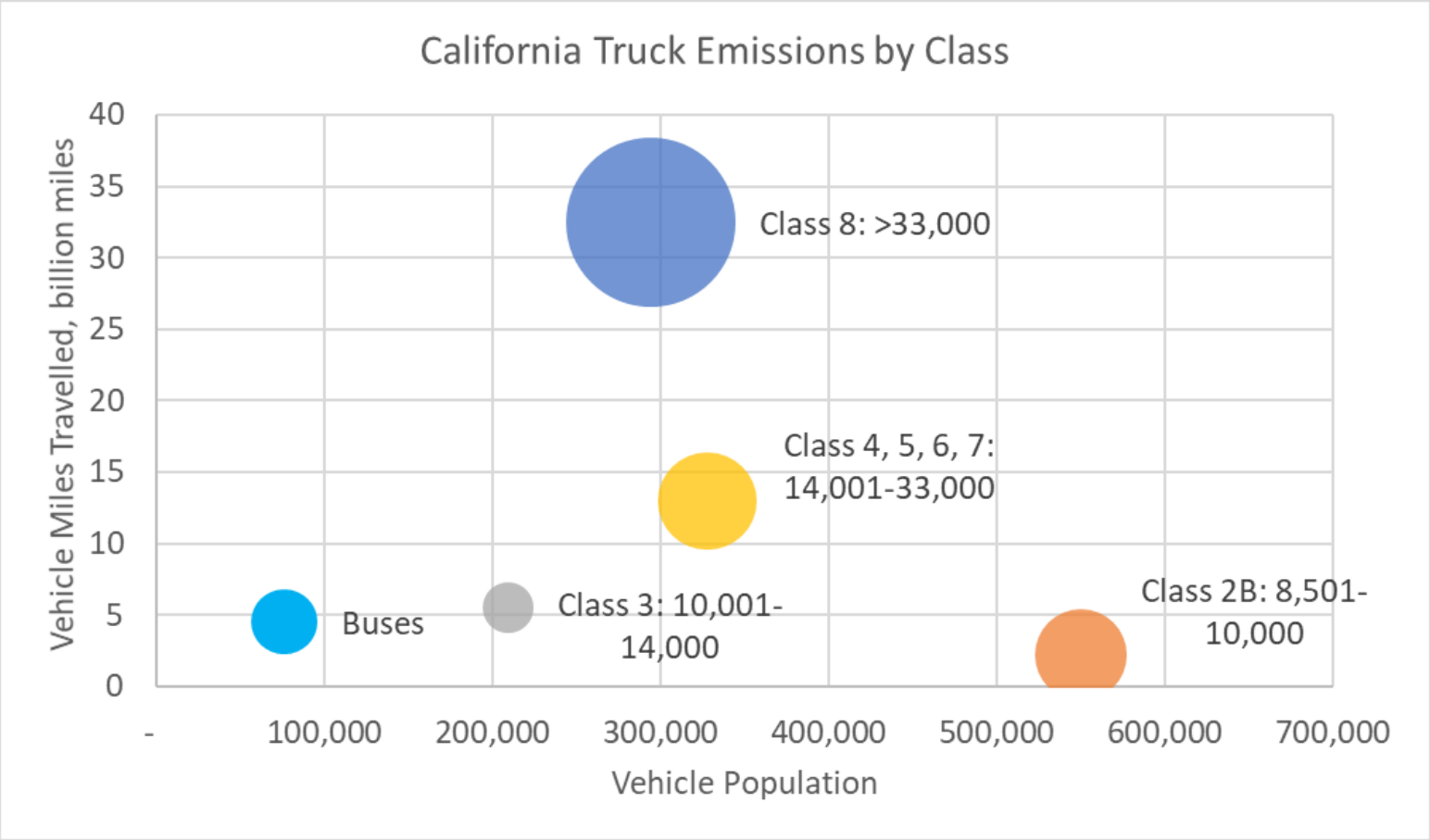
Fuel usage by weight class

FIGURE 3 FUEL CONSUMPTION BY MEDIUM AND HEAVY-DUTY VEHICLE CLASS



Source: https://www.nescaum.org/documents/heavy-duty-truck-ghg_report_final-200910.pdf

Truck emissions in California by class of truck



CalHEAT Roadmap
CaFCP MD & HD FCET Action Plan

United States emissions of combination trucks

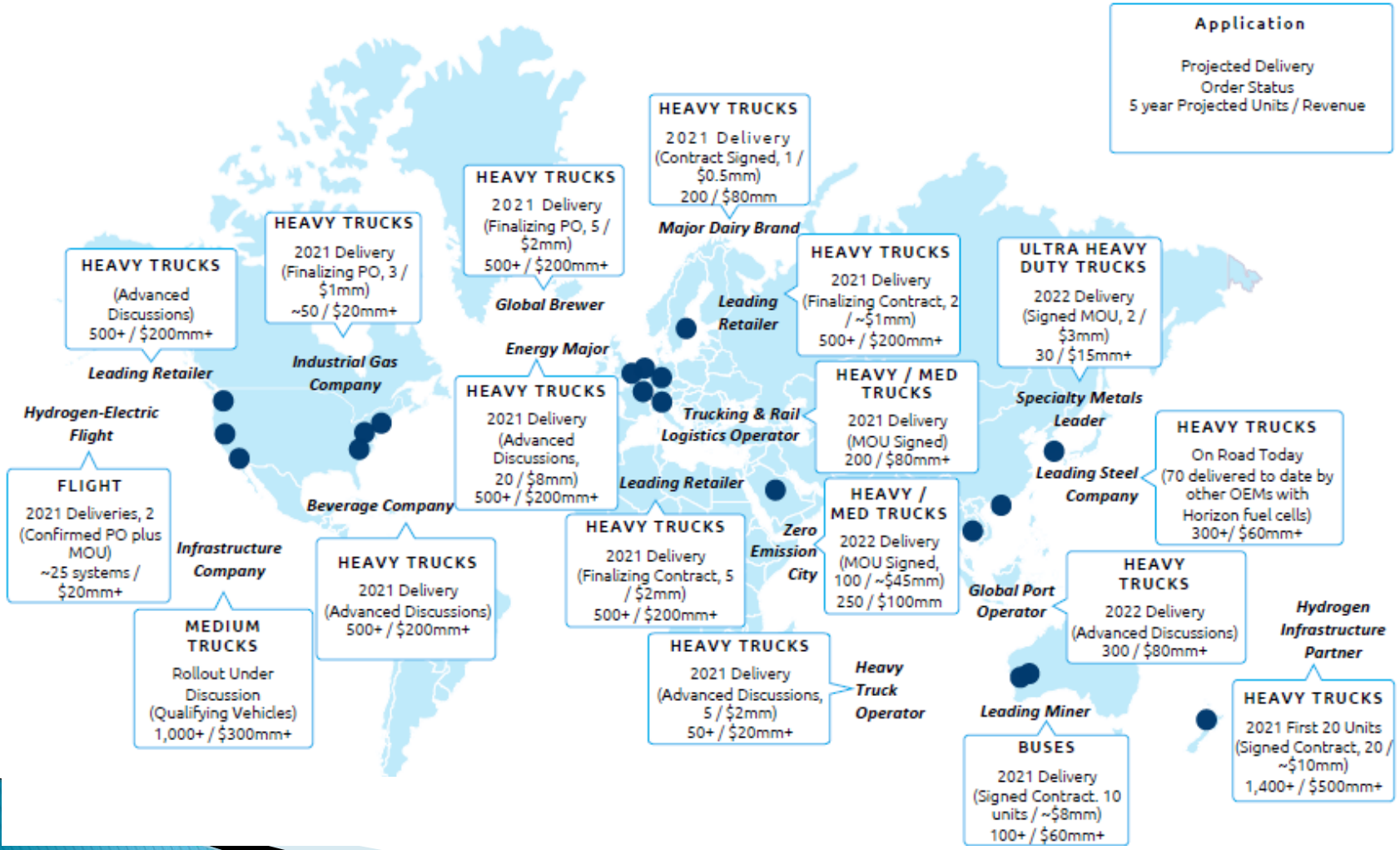
Combination Trucks	2019
Vehicle Miles Driven, millions	175,305
Registered Vehicles	2,925,210
Average Miles Driven per Vehicle	59,929
Fuel Consumed, thousand gallons	28,986,515
Average Mileage	6.0
Average Fuel Consumption per vehicle, gallons	9,909
CO2 Emissions, million tons	386.48

Source: US DOT

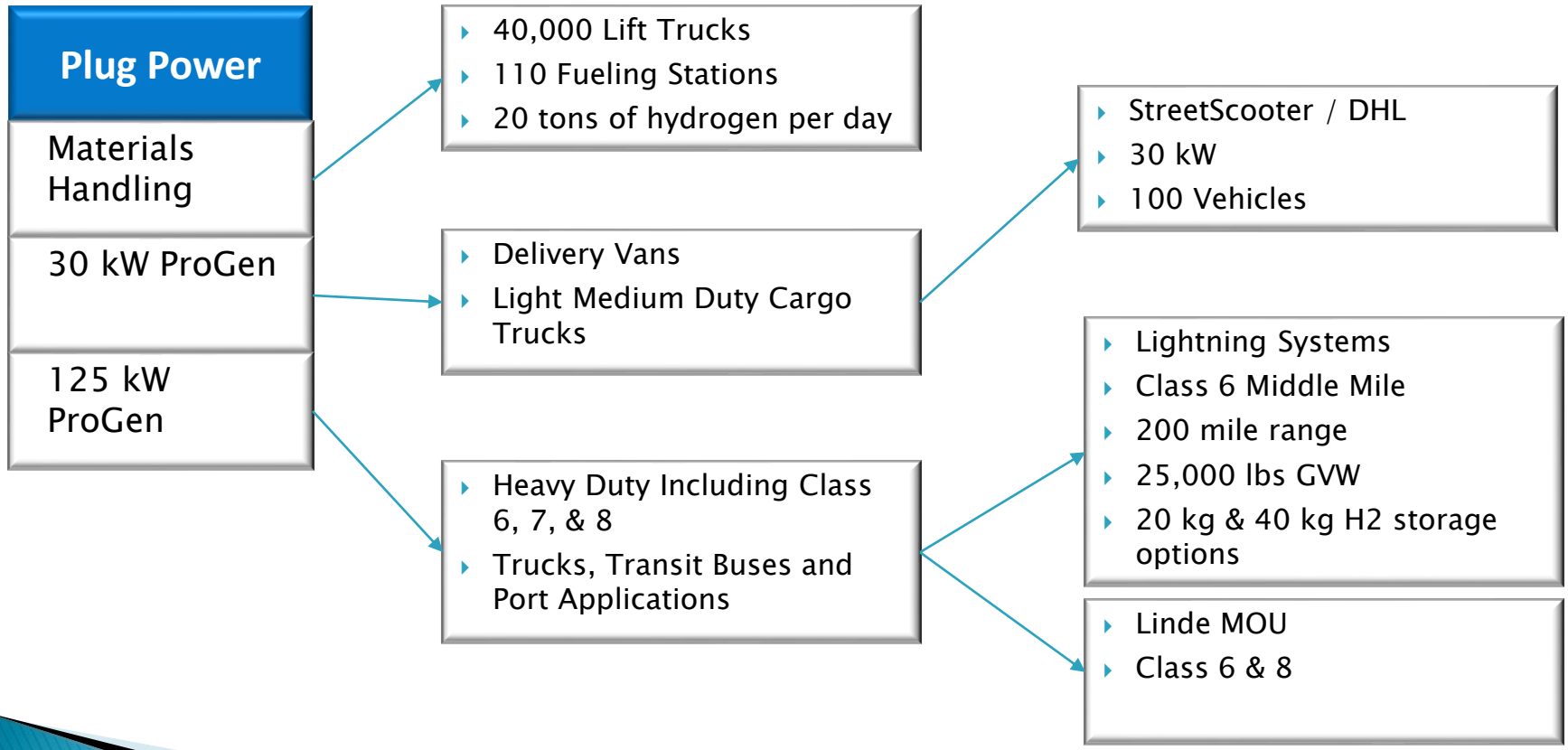
Hyzon Motors has made significant progress

- Truck and Fuel Cell System Sales by end of 2020
  - Heavy Truck 70
  - Light Truck 350
  - City Bus 5
- Building out Rochester, NY plant designed for assembling 10,000 vehicles per year
- Building out Illinois Plant for Fuel Cell Manufacturing
- Hiringa, New Zealand
  - Quantity 1,500 over 5 years
  - GVW 58 tonnes
  - Range 260 kilometers
  - Manufacture Netherlands
  - Fueling Hiringa to build out stations
    - 8 by 2022
    - 24 by 2025
    - 95% market coverage in New Zealand
    - 100 stations by 2030

Hyzon has an aggressive order book



Plug Power is aggressively entering the truck business, expanding beyond lift trucks



Plug Power Fueling

- Plans to build 5 green hydrogen stations across the United States with a capacity of 100 tons per day
  - 2 stations by 2022
  - All 5 by 2024
- 50% green hydrogen by 2024
- Agreements in place with renewable energy suppliers
  - Apex Clean Energy
  - Brookfield Renewable Partners – 10 TPD
- Announcement on 120 MW electrolyzer for Niagara, NY
  - Equivalent to producing ~50 TPD
- Other locations include Pennsylvania and Texas
- Fueling strategy is cryogenic production at source, cryogenic distribution, and cryogenic storage onsite

Ballard Power

- Current deployments
  - 1,000 fuel cell electric buses
  - 2,200 commercial trucks
- DongFeng Special Vehicle Co. Ltd.
  - Logistics – city deliveries, box van trucks
  - Gross Vehicle Weight: 7.5 ton
  - Range: 205 miles
  - Fuel Cell Power: 30 kW
  - Location: Shanghai, China
  - Payload: 3.2 tons
- AZETEC – Alberta Zero Emission Truck Electrification Collaboration Project
  - Quantity: 2
  - Gross Vehicle Weight: 64 tonnes
  - Vehicle: B-Train tractor trailers
  - Range: 430 miles
  - Fuel Cell Power: 3X70 kW = 210 kW/vehicle
- Anglo American, South Africa
  - Ultra Class heavy duty mining truck
  - Fuel Cell Power: 8X100 kW = 800 kW

Hyundai

- Switzerland
  - Delivered 10 Xcient FCE trucks to Switzerland in October, 2020
  - Order of 50 complete by the end of 2020
  - 1,600 by 2025
  - Fuel Cell Power — 2X95 kW = 190 kW
  - Tanks — 7 tanks
  - Storage — 32.09 kg
  - Range — 250 miles
  - Fill up time — 8 – 20 minutes
- Fueling
  - Agreement with H2 Energy
  - Jointly build fueling stations across Switzerland for cars and trucks
  - Plan to source hydrogen from hydropower

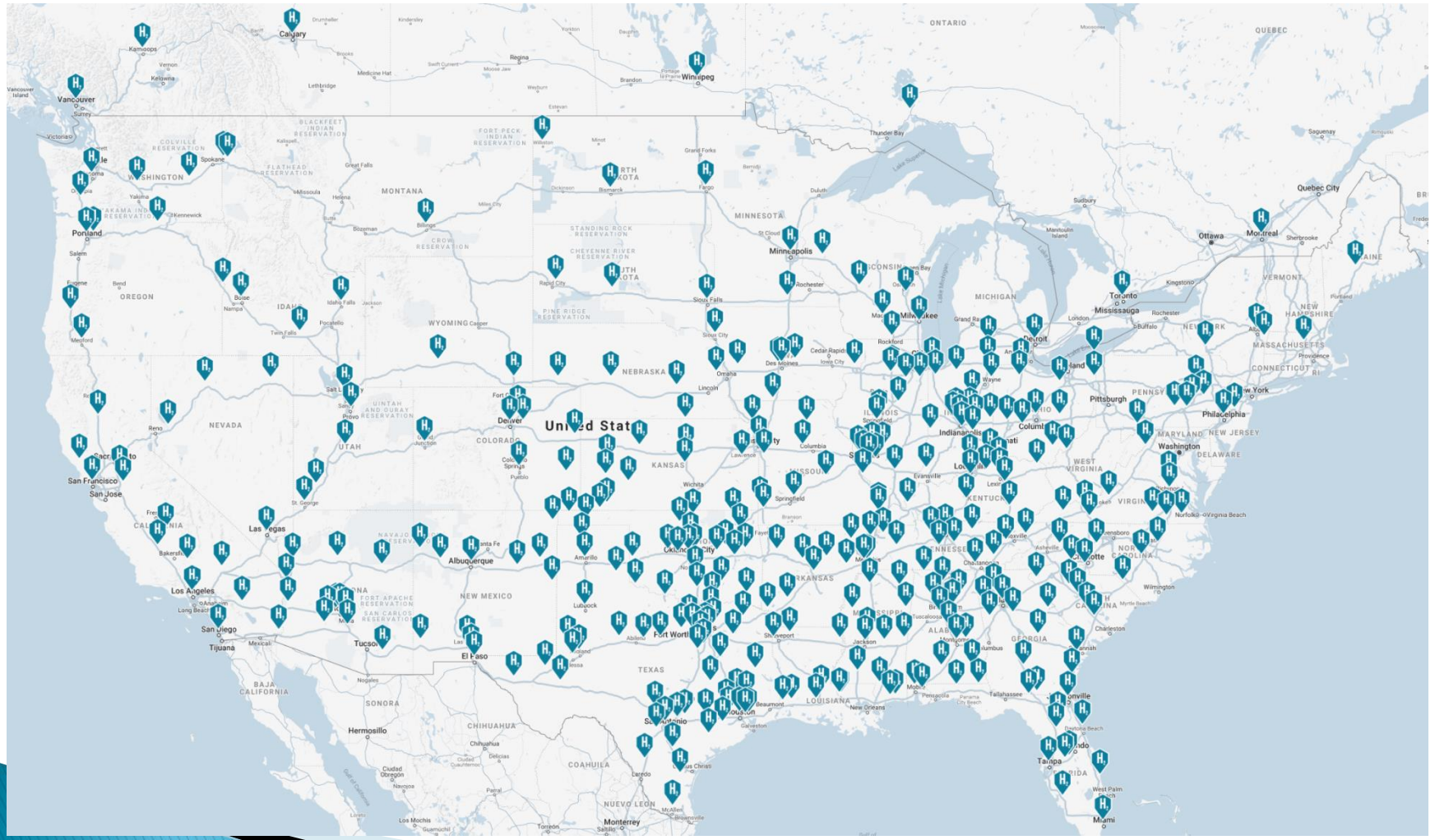
Fueling Strategies

- Hyzon Motors
  - 2021: 95% On-site customer supply, 5% existing stations
  - 2021-2024: Hyzon created capacity for 25%, 75% on-site and existing stations
  - After 2024: Hyzon Network 50%, 3rd party capacity 50%
- Plug Power
  - Liquid hydrogen production from renewable sources
  - Distributed and stored on fueling site in liquid form
  - Partnerships with Apex, Brookfield and Linde
  - Acquired Giner for electrolysis
- Nikola
  - Sourcing inexpensive electricity where available
    - Arizona Public Service quoted at 2.7 cents/kWh
  - Transporting hydrogen in liquid or gaseous form where needed
  - Plans to build stations, current estimate at $16 million per station and targeting $10 million per station buildout
  - Bundling cost of truck, maintenance and fuel for customers in a 7 year lease and 1 million miles
  - Nikola, IVECO and OGE to build 124 mile pipeline for distributing hydrogen to fueling stations
  - Nikola plans a network of 700 hydrogen stations across the U.S. and Canada by 2028

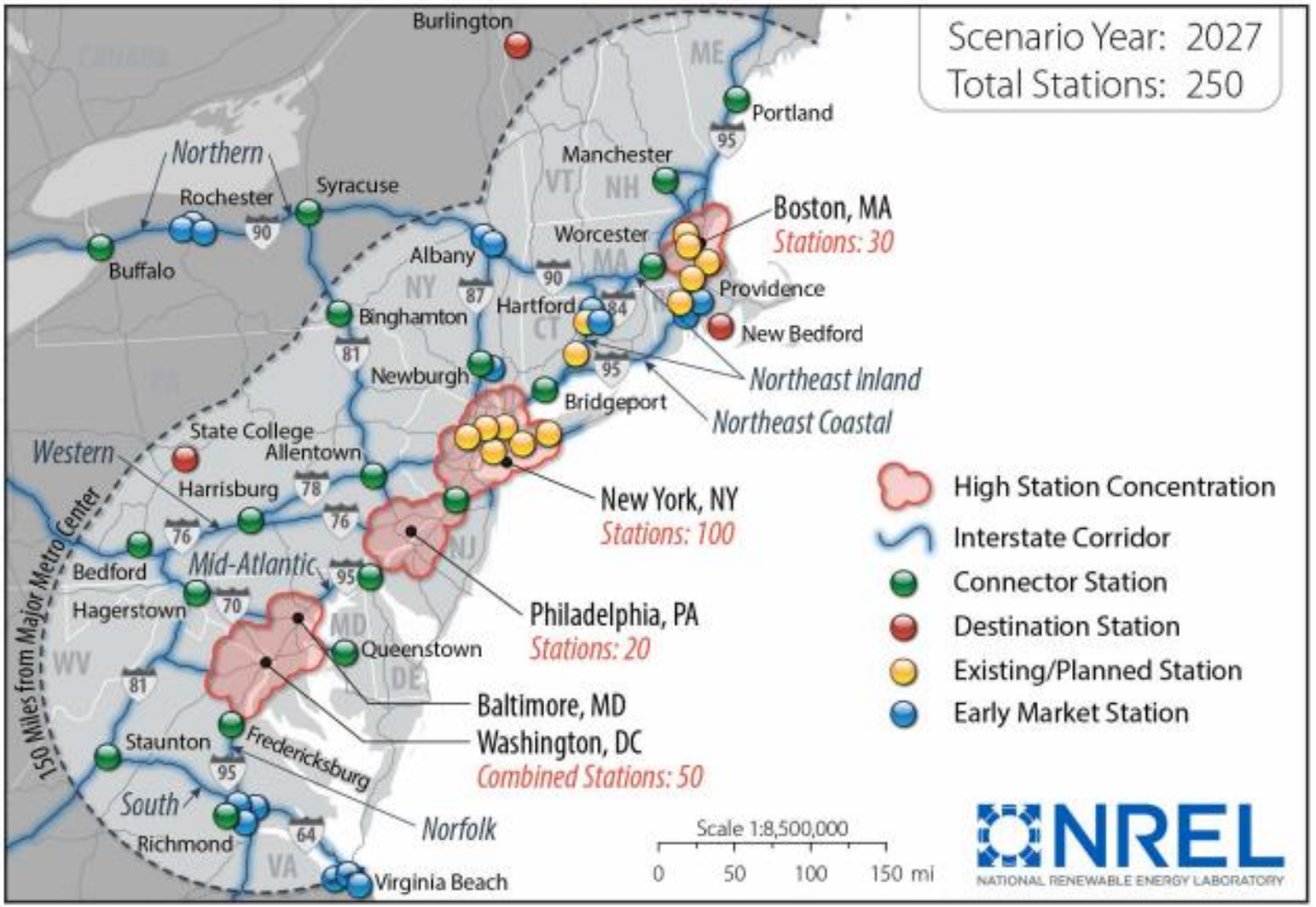
Fueling Strategies

- Daimler
  - Liquid on board storage
- Air Liquid
  - Liquid hydrogen production at central facilities and distributed to fueling depots
  - Distribution from fueling depots in gaseous form to hydrogen filling stations

Nikola Motor planned hydrogen refueling stations



2027 Northeast Hydrogen Station Deployment Plan – H2USA



Battery Weight and Cost Challenges for 18 Wheelers

- Diesel
  - 18 wheeler “day cab” 32,000 lbs
  - Payload 48,000 lbs
  - GVW 80,000 lbs
- Battery Electric
  - 500 mile range @ 2 kWh/mile = 1,000 kWh
  - 80% draw down limit on battery implies 1,250 kWh requirement
  - Battery plus pack weight at 14 lbs/kWh = 17,500 pounds
  - Payload = 48,000 lbs – 17,500 lbs = 30,500 lbs
- FCE Truck
  - Additional weight of tanks, etc. is approximately 4,000 pounds heavier than diesel
  - Payload = 48,000 lbs – 4,000 lbs = 44,000 lbs
- Battery Cost
  - 1,250 kWh @ $150 per kWh (cells plus pack) = $187,500

Fuel Cost

- Diesel
  - Cost per gallon — $2.89
  - Miles per year — 85,000
  - Efficiency — 6 miles per gallon
  - Annual fuel cost — $40,942/year
- FCE Truck
  - Cost per kilogram — $4
  - Miles per year — 85,000
  - Efficiency — 7.5 miles per kg
  - Annual Fuel Cost — $45,333
- Battery Electric Truck
  - Cost of electricity — $0.12/kWh
  - Miles per year — 85,000
  - Efficiency — 2 kWh/mile
  - Annual cost — $20,400