NC STATE UNIVERSITY

SUSTAINABLE FLEET TECHNOLOGY CONFERENCE & EXPO 2023

# Track B Session 3: Advancements in Engines, Powertrains, and Batteries

August 15, 2023

NC CLEAN ENERGY TECHNOLOGY CENTER

STATE OF NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

CORNING

Sustainable Fleet Technology Conference 2023

# *Advancements in Engines, Powertrains and Batteries*

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Date : August 16th, 2023

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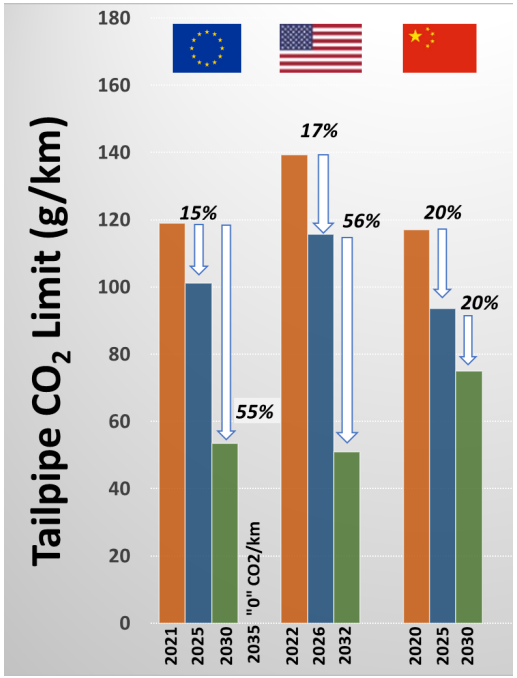
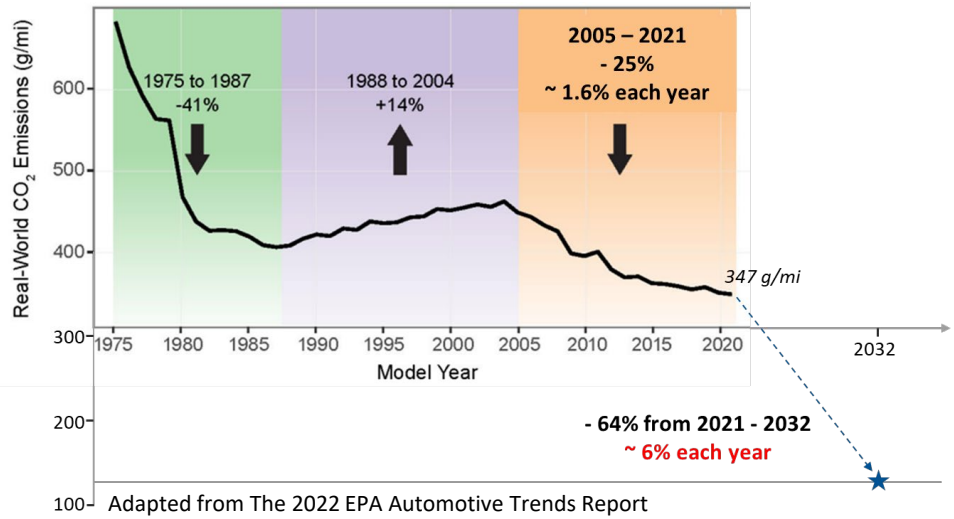
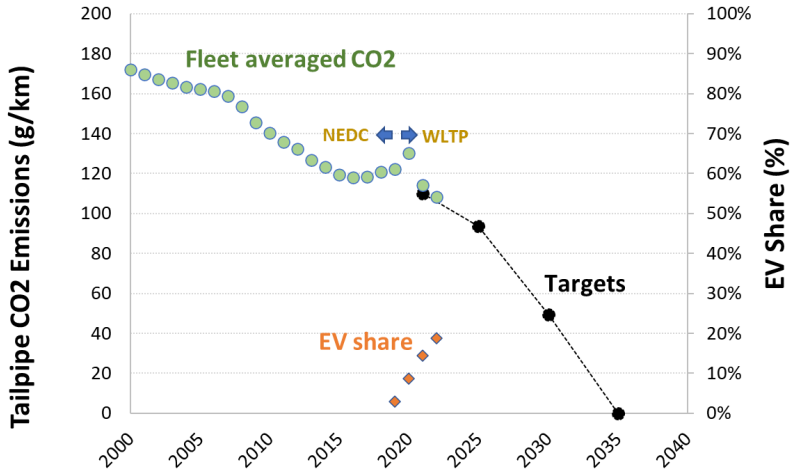
# $CO_2$ standards are driving a rapid change in transportation



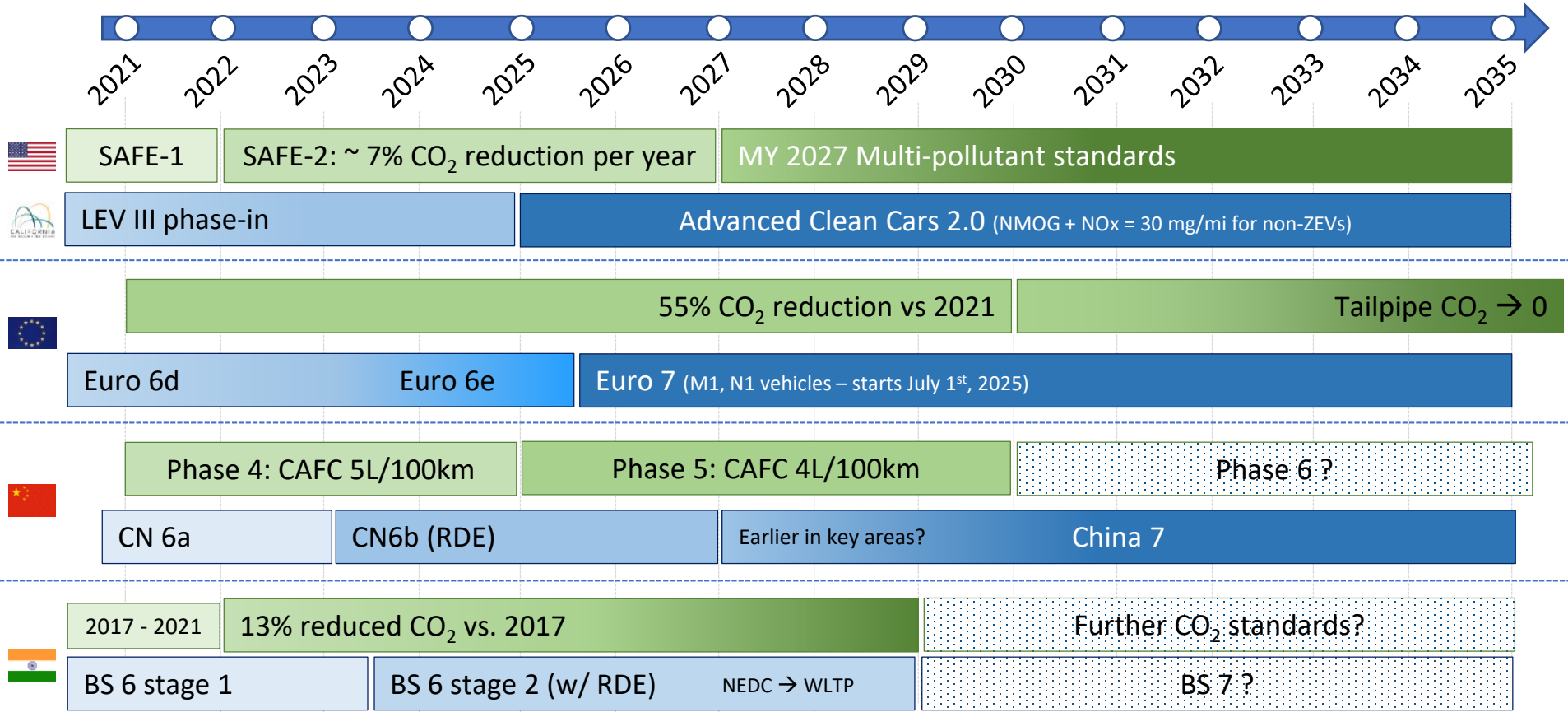




Adapted from The 2022 EPA Automotive Trends Report




Adapted from the European Env. Agency report, 2023

# The industry has to meet both criteria emission and fuel economy requirements … in a diverse, global market

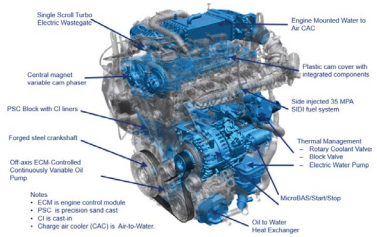


# Don’t give up on engines just yet … a few advancements shown in the last year

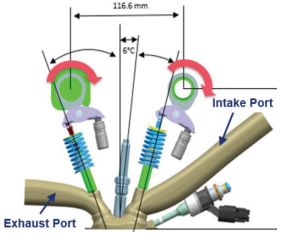
*1.5L* *2.0L* *3.0L*

## GM, 4-cyl. GDI for China 6b

GM, 43rd Intl. Vienna Motor Symposium, 2022



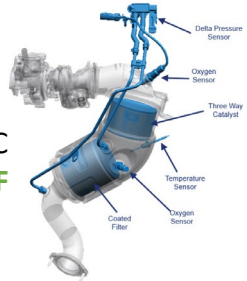

CR 10:1
100 kW/L
Min. BSFC 230 g/kWh




**350 bar DI**, **multiple injections** at low engine speed. Inlet port designed for optimum tumble

Paired with **48V mild hybrid**

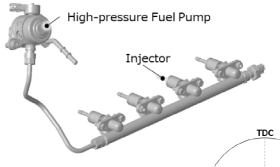

cc-TWC
+ **c-GPF**



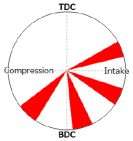

## Honda, 4-cyl. GDI

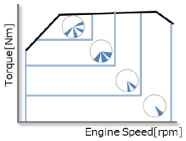
Honda, 31st Aachen Colloquium Sustainable Mobility 2022

CR 13.9
Peak BTE 40.6%

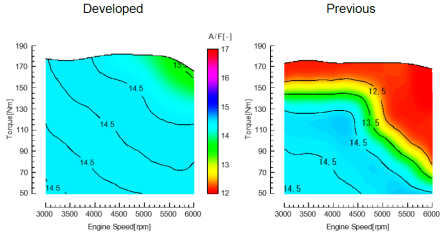



**350 bar & multiple injections** after cold-start



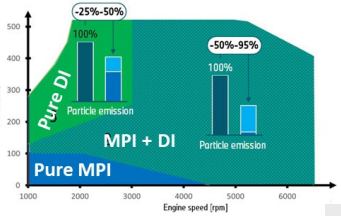

Extended λ=1 for lower CO emissions




## BMW 6-cyl. GDI + MPI

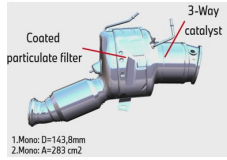
BMW, 31st Aachen Colloquium Sustainable Mobility 2022

Fuel consumption ↓ by 1L/100 km (~ 10%)
CR 11:1, Miller (EIVC)
λ = 1 over entire map
Min. BSFC 224 g/kWh



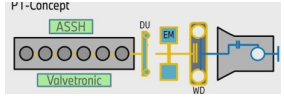

44% lower engine out PM
Dual injection
**350 bar DI + MPI**

**Very high FE GPF**




Electrically actuated cam phaser - Faster response for lower cold start emissions

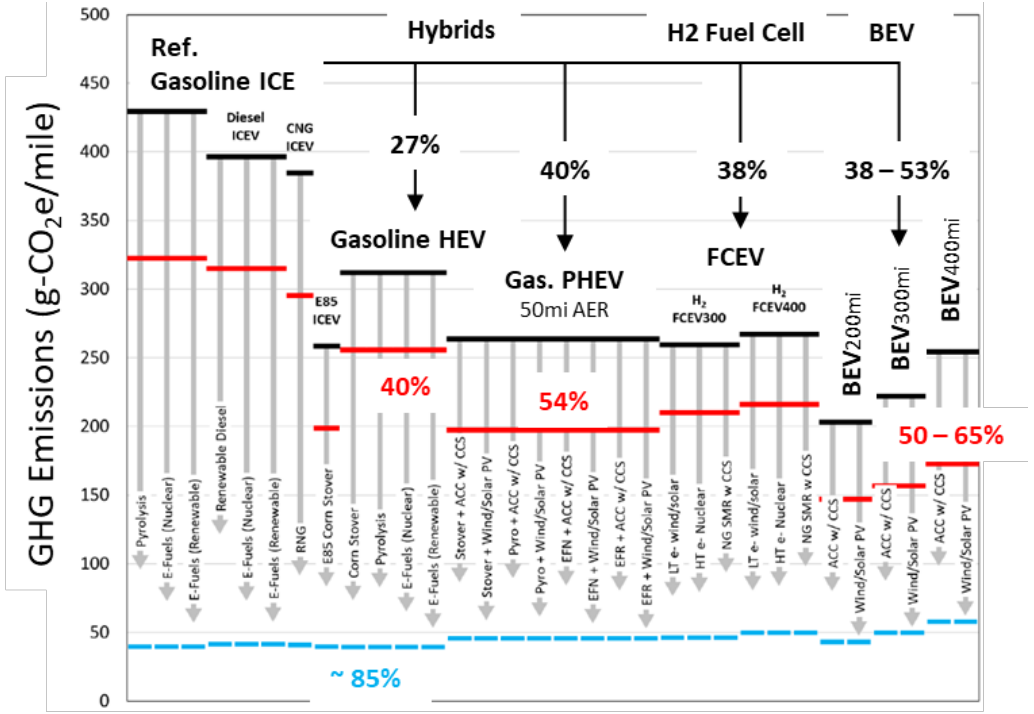
**48V mild hybrid**



# Cradle-to-Grave analysis
# Multiple pathways to address transport decarbonization

Argonne National Lab
https://greet.es.anl.gov/publication-c2g_lca_us_ldv

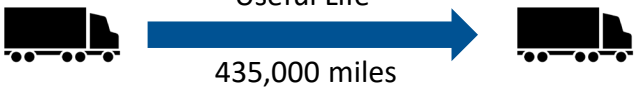
GHG Emissions for small SUVs
Current
Future (2030 – 35) technology
Advanced Fuels



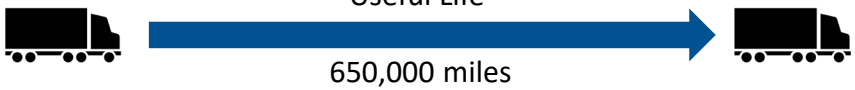
# New heavy-duty low NOx regulations will require advancing ICEs

## EPA Clean Trucks Plan

**Today**



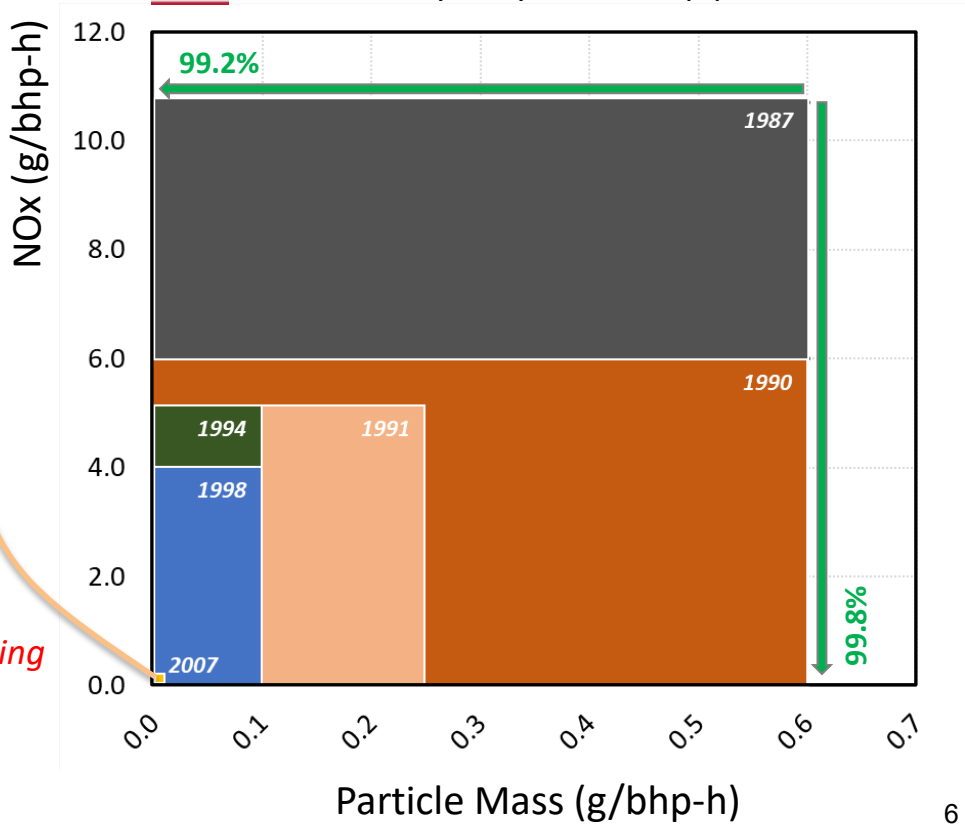

**2027**




+ Low load cycle
+ PM 50% reduction
+ In-use compliance
+ GHG Phase 3

*+ 82% NOx reduction starting MY2027*

US EPA heavy-duty diesel tailpipe standards



# And the industry must also pursue decarbonization technologies

To BE or not to BE?
… is no longer a question

## California Advanced Clean Trucks Regulation

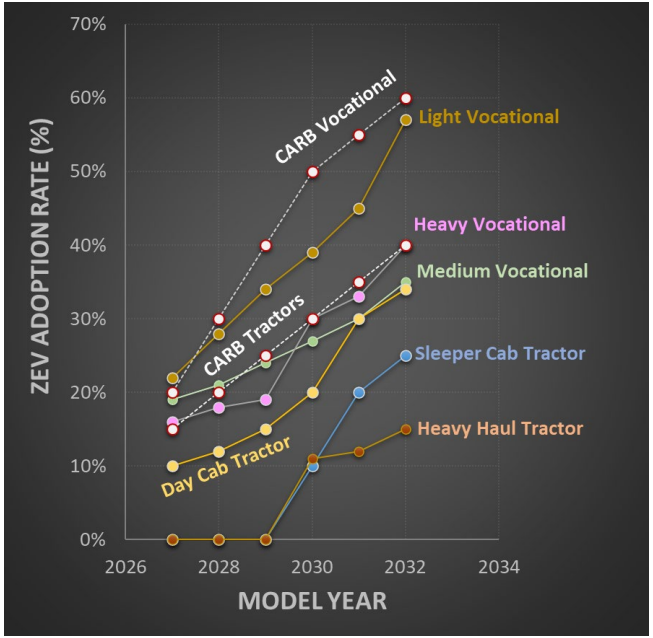
Manufacturer ZEV* requirements as % of annual sales

| Model Year (MY) | Class 2b-3 | Class 4-8 | Class 7-8 Tractors |
|---|---|---|---|
| 2024 | 5% | 9% | 5% |
| 2025 | 7% | 11% | 7% |
| 2026 | 10% | 13% | 10% |
| 2027 | 15% | 20% | 15% |
| 2028 | 20% | 30% | 20% |
| 2029 | 25% | 40% | 25% |
| 2030 | 30% | 50% | 30% |
| 2031 | 35% | 55% | 35% |
| 2032 | 40% | 60% | 40% |
| 2033 | 45% | 65% | 40% |
| 2034 | 50% | 70% | 40% |
| 2035+ | 55% | 75% | 40% |

* ZEVs defined as vehicles with zero tailpipe $CO_2$ (BEV, FCEV)

## US : GHG Phase 3 Proposal

Projected ZEV penetration



# Heavy duty engines serve diverse vehicle applications
## - Decarbonization will require a range of technology solutions

*Total in-use ~ 23 million*

| % GHG | % NOx | % Fleet |
|---|---|---|
| 48% | 47% | 9% |
| | | 5% |
| | | 34% |
| 12% | 13% | 1% |
| | | 2% |
| 22% | 20% | 49% |
| 2% | 3% | |
| 1% | 1% | |
| 16% | 17% | |

Long haul tractor ~ 300 - 500 mi

Regional haul tractor
~ 150 – 300 mi

Vocational ~ 50 – 150 mi

Transit bus ~ 150 mi

School bus ~ 100 mi

HD pickup / van ~ 50 – 75 mi

*Vehicle Class*

- Class 7 - 8
- Class 3 - 7
- Class 7 - 8
- Class 2b - 3

*Fuel type*

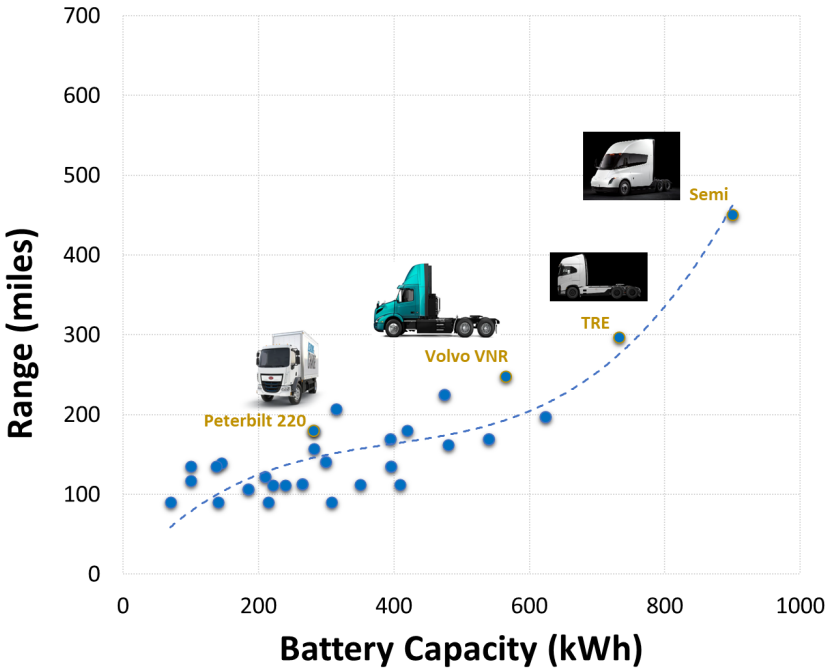
Diesel
Gas
Other



# Long-haul trucking : Need to advance megawatt charging & $H_2$ delivery

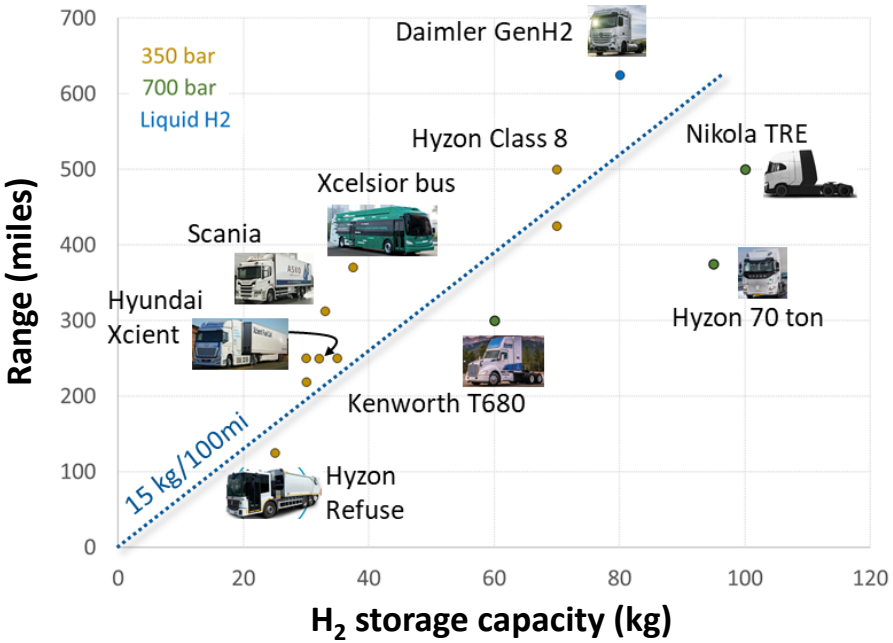
## Battery Electric Trucks

**~ 1MWh battery pack needed for 500+ mile range**




## $H_2$ fuel cell trucks

**Need to significantly increase green $H_2$ production**




For ~ 0.5M long-haul trucks running 350 mi per day, $H_2$ annual requirement = ~ 9.6M tons

US total $H_2$ demand today is 10M tons per year, almost all made from fossil fuels

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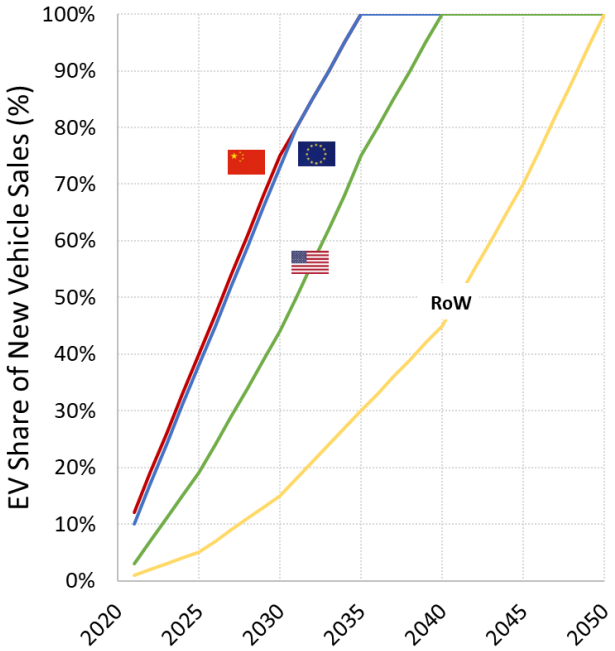
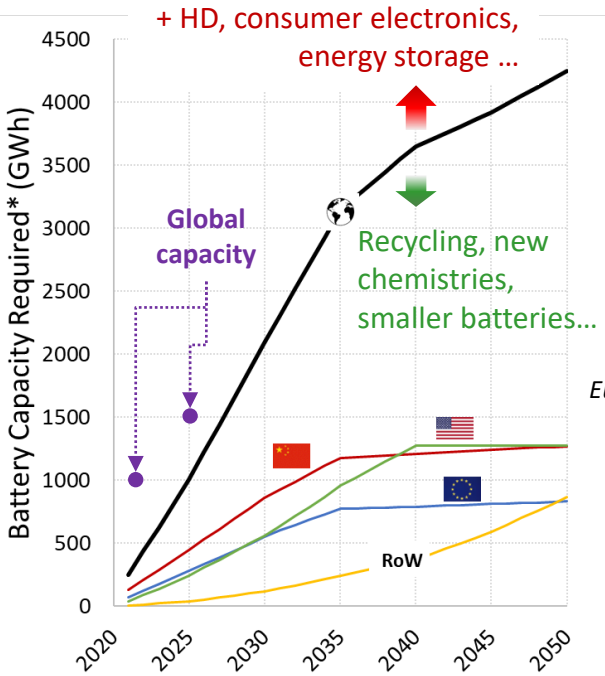
# Battery raw materials could be a bottleneck for EVs in the next few years

## EV share (light-duty)



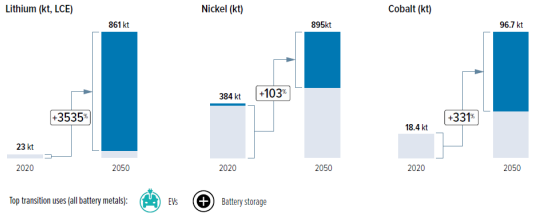

## Battery demand for LD




## Raw materials

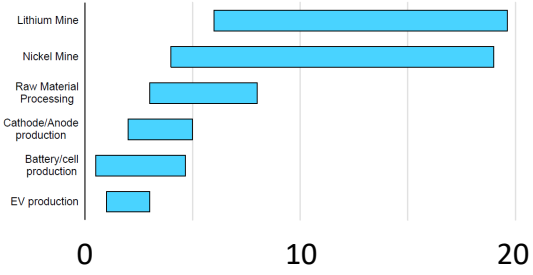
Future needs for EU alone

Li : 36X  Ni : 2X  Co : 4X




*"Metals for Clean Energy: Pathways to solving Europe's raw materials challenge"* Eurometaux, 2022

Mines cannot be built overnight




<u>Assumptions</u>

Avg. battery pack sizes – 50 kWh in China, 60 kWh in Europe, 75 kWh in US

Vehicle sales flat in US and grow at 0.5% per year in all other regions

No separation of PHEV and BEV for simplicity

# Several technology choices to reduce well-to-wheel $CO_2$ emissions - Each with their pros and cons

| | IC Engine (Ref.) | Low C Fuels | BEV | $H_2$ Fuel Cell | $H_2$ ICE |
|---|---|---|---|---|---|
| *GHG Reduction* | Ref. | ++ | ++ | ++ | ++ |
| *Fueling Infrastructure* | Ref. | o (Ready) | -- | --- | --- |
| *Refueling Time* | Ref. | o | -- | o | o |
| *Range* | Ref. | o | -- | o | o |
| *NOx/PM emissions* | Ref. | o | +++ | +++ | + |
| *TCO* | Ref. | --- | ++/-- (*) | ++/-- (*) | -- |
| *Critical materials* | Cat. only | - | - | - | o |
| *Existing fleet* | Ref. | Yes | No | No | No |

(*) Depends on application and various assumptions

# Super-Truck II : 55% BTE & 2X freight efficiency ✓





| Daimler | Volvo | Cummins / Peterbilt | Navistar | PACCAR / Kenworth |
|---|---|---|---|---|

https://www.energy.gov/eere/vehicles/annual-merit-review-presentations

## Improved combustion

High CR + 0.3 – 0.8 BTE
Thermal barrier coatings - 1 % BSFC
Lower friction +0.5% BTE

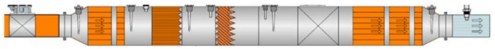
## Improved air handling

*Eaton*

EGR pump (+0.9 BTE)
Miller cycle LIVC
High efficiency turbochargers

**ENGINE**

## Improved after-treatment



*Navistar*

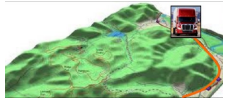
Low ΔP design
cc-SCR, high cell density, thin wall

## Waste heat recovery

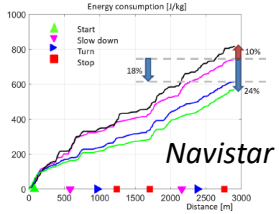
Exhaust Tailpipe ORC Evaporator

~ +3 – 4.5% BTE
ORC with cyclopentane
Dual entry turbine

## Model-based control



## Predictive cruise control




*Navistar*

**VEHICLE**

## Weight reduction

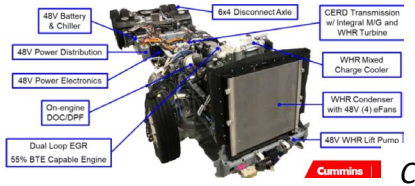
Navistar: ~ 4,000 lbs (trailer, frame)
Cummins: ~4,700 lbs (+ trailer solar panels)
PACCAR: 28%

## Aerodynamics & tires

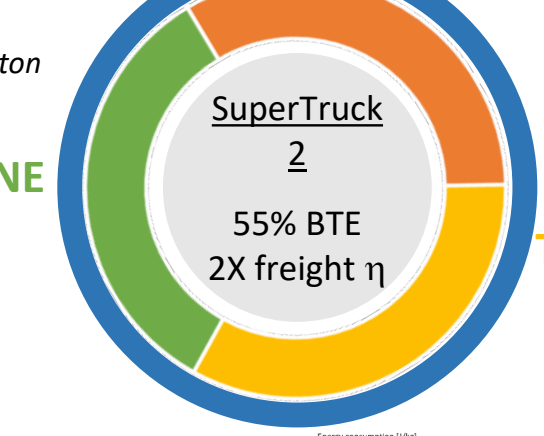
Aero drag reduced by ~ ~60% by NAV, Kenworth, Cummins, PACCAR
Rolling R : NAV 22% ↓, Cummins 33% ↓

**TRANSMISSION, ELECTRIFICATION**

48V mild hybridization, 7 – 15 kWh Li-ion battery. Electrification: HVAC, P-steering, coolant pumps, CAC, e-hoteling, etc.




*Cummins*



# We need to pursue all pathways for transport decarbonization

Detroit DD15, inline 6-cyl
2024 GHG compliant

**Efficiency improvements**
55% BTE, Opposed piston

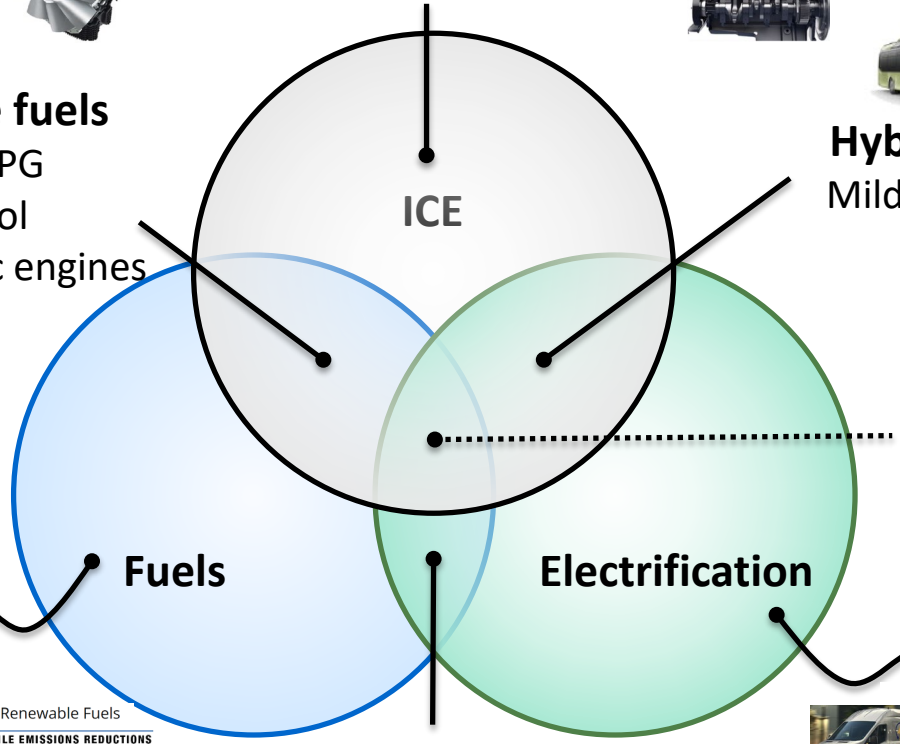
AchatesPower Opposed
Piston engine

Volvo 7900 hybrid

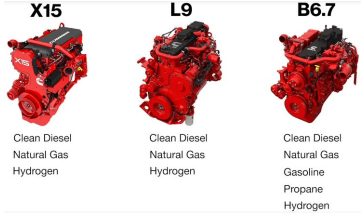
ClearFlame Engine
Runs on ethanol

**Alternate fuels**
CNG, LPG
Ethanol
Fuel agnostic engines

**Hybridization**
Mild, full hybrid




Cummins
fuel agnostic
engines




**Hybrid + green fuel**
$H_2$ ICE
Plug-in + Syn fuel

Cummins
15L $H_2$ ICE

**Low carbon fuels**
Renewable fuels

Phillips 66 Makes Final Investment Decision to Convert San Francisco Refinery to a Renewable Fuels Facility

*May 11, 2022*

*It will be one of the world's largest facilities of its kind; expected to begin commercial operation*

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MOBILE EMISSIONS REDUCTIONS

↓ 8 million
metric tons per year of lifecycle carbon emissions reductions, the equivalent of taking 1.4 million cars off the road

**Synthetic fuels**
e-diesel

**ZEVs**
Battery electrics
Fuel cell vehicles

# Thank you !

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ACCURE
Battery Intelligence

# **Battery health and safety:** monitoring technology for electric vehicles

Brett Stein

August 16, 2023

SUSTAINABLE FLEET TECHNOLOGY
CONFERENCE & EXPO 2023

# Electrification of transportation brings new challenges in terms of safety, performance and lifetime

## Safety

- **Battery fires are common:** Thousands of fires every year, from cars to commercial vehicles
- **Insurance premiums are high:** damages are not fully covered and costs balloon after incidents

## Performance

- **BMS errors and suspect production quality control** leading to vehicles performing out of specification
- Downtime and underperformance (e.g., SOC errors) result in **major financial losses**

## Lifetime


- **Increasing warranty requirements** like in California put pressure on OEM
- **Warranty management and compliance** across vendors becomes increasingly complex for OEM

DATA-CENTRIC APPROACH

# Cloud analytics improve safety and operational efficiency using readily available Battery Management System data

## Safety

- Early safety risk detection
- Automated alerts and logging
- Improved warranty conditions

> 50 incidents prevented in 2022

## Performance

- Underperformance and downtime
- Predictive maintenance
- Track and improve SOC accuracy

Numerous successful warranty claims

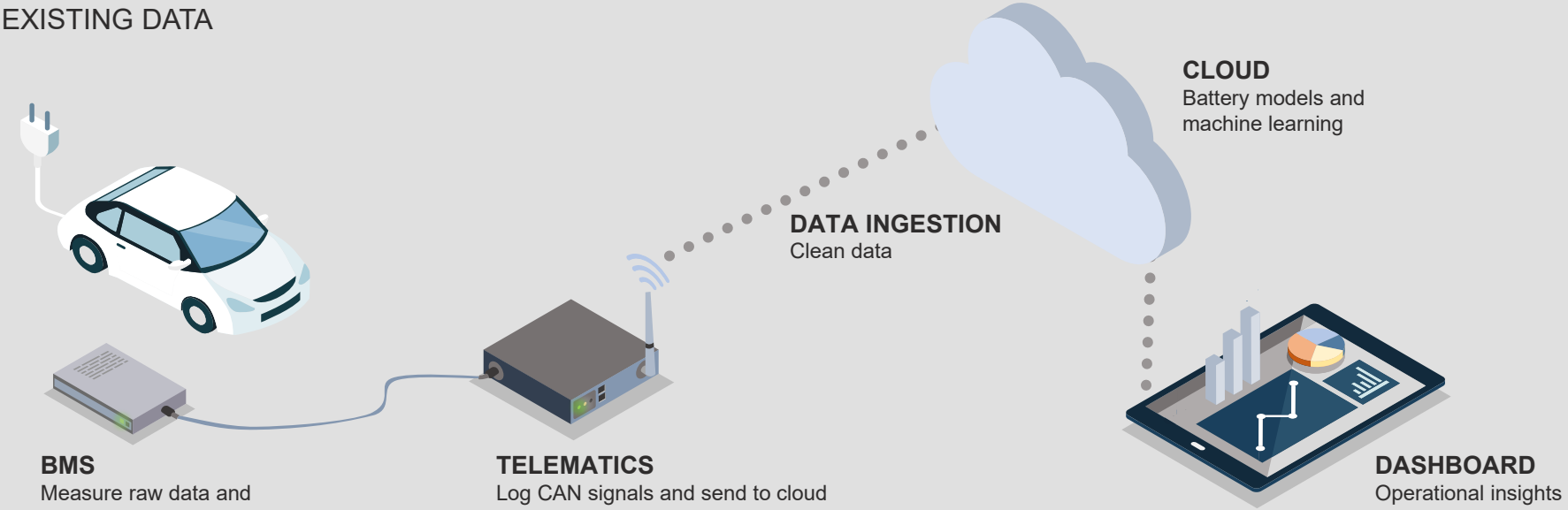
## Lifetime

- Degradation & SOH insights
- Warranty claims management and compliance

> 25% lifetime increase

# Predict the safety, performance, and lifetime of EV batteries

EXISTING DATA




**Readily available BMS data** is underused today.

# Real-world example: Detect battery issues before they become critical.

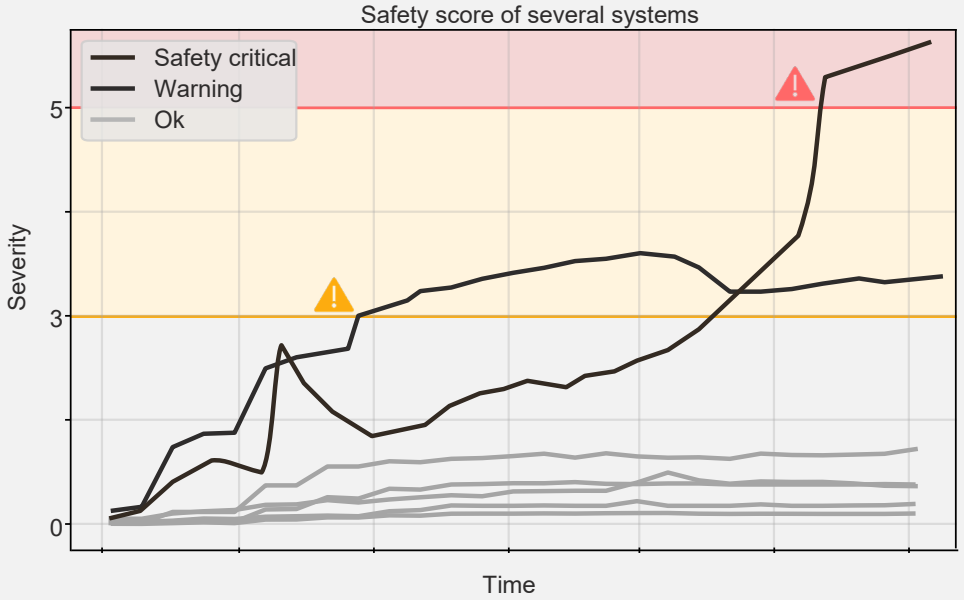
**Safety-first approach to asset management**

**What:** A Lithium-Ion battery failure can result in gassing and burning, potentially harming people and property. Critical battery incidents include cell openings that release toxic gasses, such as hydrofluoric acid, as well as internal short circuits and fires.

**How:** By tracking long-term indicators which are often missed by the BMS, we can:

- Detect safety-relevant patterns and anomalies and
- Identify sudden failure events

This allows for a proactive asset management strategy rather than a reactive one.



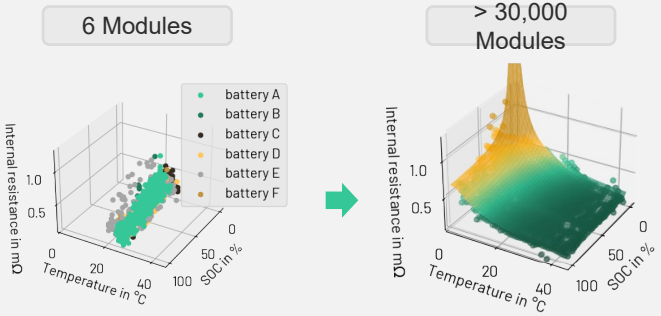
# Real-world example: Using cloud computing to predict battery failures related to performance and fast-charging capabilities

## Predictive capabilities

**What:** A rapid increase of the internal resistance limits vehicle performance and fast-charging and leads to battery failures. This can be predicted by big data algorithms.

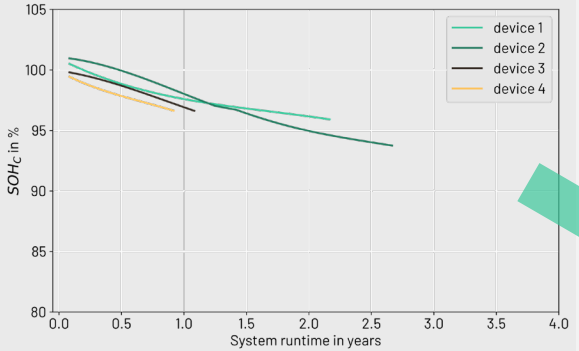
**How:**

- The internal resistance of EV batteries strongly depends on internal and external factors, including ageing, temperature and state of charge.
- ACCURE's analytical framework allows to track and predict the internal resistance for all operating conditions based on the overall vehicle fleet




## Cloud-based capabilities manage noisy data

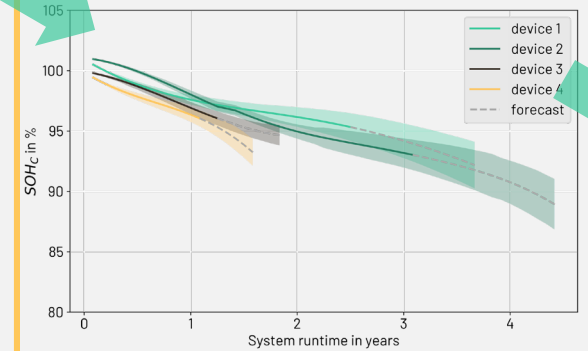
# Real-world example: High accuracy state-of-health prediction to predict failure rates due to accelerated ageing behavior



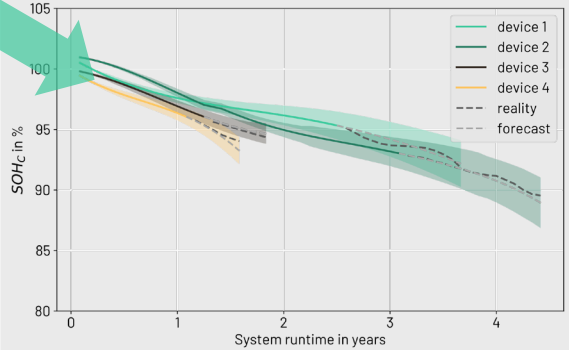

**Nowcasting** of battery state-of-health ($SOH_C$) to assess current fleet status

Focus for failure rate prediction

**Forecasting** of battery state-of-health ($SOH_C$) based on nowcasting results to **predict and prevent early end-of-life failures**




**Validation:** State-of-health predictions are field proven and tested against a variety of use cases



CASE STUDY: BERLIN TRANSIT AUTHORITY

# We detected a critical safety issue preventing a potentially dangerous situation.

*BVG, one of the largest transit operators in the world, was managing a large and very complex electrification project.*

## Background

- Partnered with ACCURE to actively monitor 15 electric buses.
- We identified a critical safety issue and alerted BVG. On the same day, BVG removed the bus from operation.

## Solution

- In a post-mortem review, the battery problem was proven to be a critical failure situation.
- The BMS did not identify the problem.
- BVG requested ACCURE's continuous monitoring.

CASE STUDY: NEW YORK CITY TRANSIT

# We remotely detected previously unknown battery resistance issues.

*New York City Transit is North America's largest and busiest transit system and is transitioning to a zero-emissions bus fleet.*

## Background

- ACCURE was selected from hundreds of applicants to participate in the highly competitive Transit Tech Lab pilot program
- We would use readily available BMS data from 15 electric buses and provide NYCT with insights into fleet safety and performance.

## Solution

- ACCURE found four buses with battery capacitance/resistance issues, which has resulted in operational underperformance.
- NYCT is taking a proactive approach to battery asset management which will extend the useful life of its bus fleet.
- ACCURE and the NYCT have successfully completed the Transit Tech Lab program and are exploring the next steps.

ACCURE


MTA New York City Transit

# Leverage battery data for safe, efficient electrification.

Brett Stein
b.stein@accure.net
+1 917.770.0267

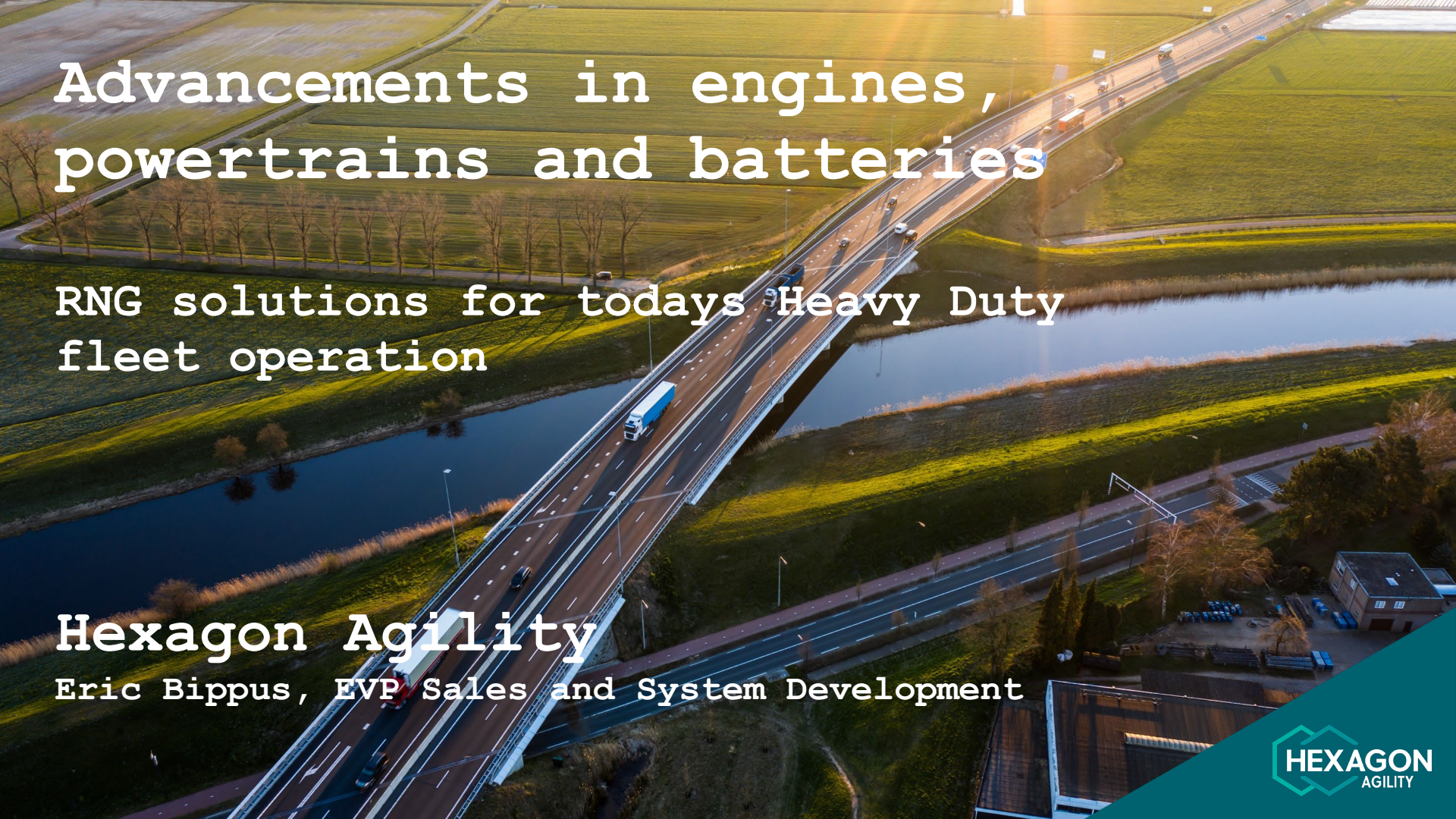
**2.6+ GWh**
managed

**>100m Cells**
actively monitored

**100+ Battery types**
chemistries, models

**1 Petabyte**
data handled

**35+ Battery Experts**
partnering with you



# Advancements in engines, powertrains and batteries

## RNG solutions for todays Heavy Duty fleet operation


**Hexagon Agility**

Eric Bippus, EVP Sales and System Development


HEXAGON AGILITY

# Hexagon – A global leader in clean energy storage and solutions

## HEXAGON AGILITY

(Renewable) Natural Gas

Mobility

Gas infrastructure

## HEXAGON PURUS

38% Equity

Hydrogen and battery-electric solutions

Mobility

Gas infrastructure

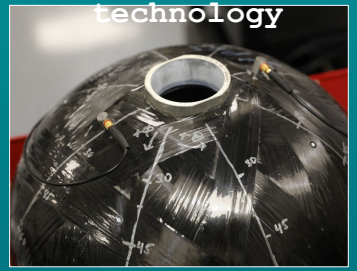
## HEXAGON RAGASCO

LPG cylinders

Home, leisure and small industrial applications

## HEXAGON DIGITAL WAVE

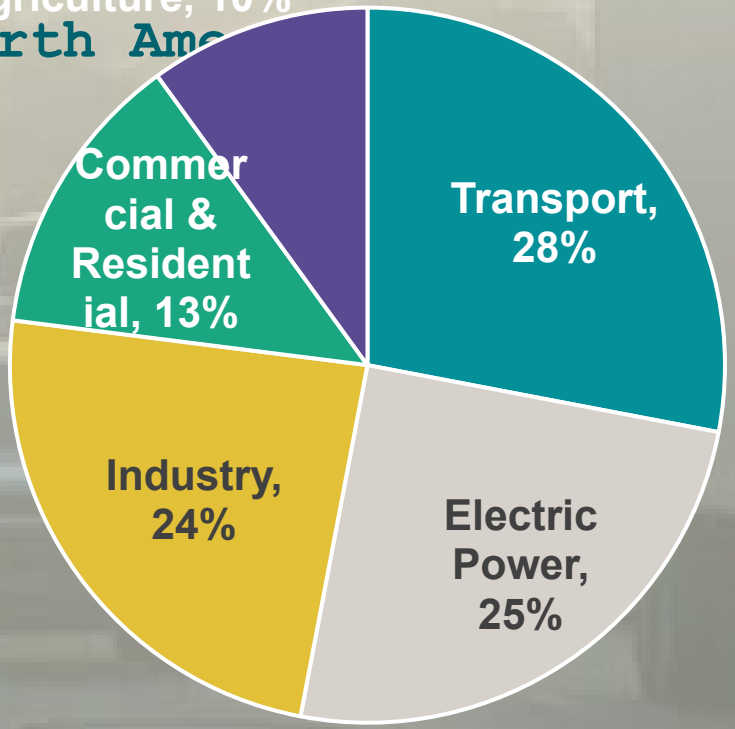
Cylinder testing and monitoring technology



Serves the compressed gas and pressure vessel industries.

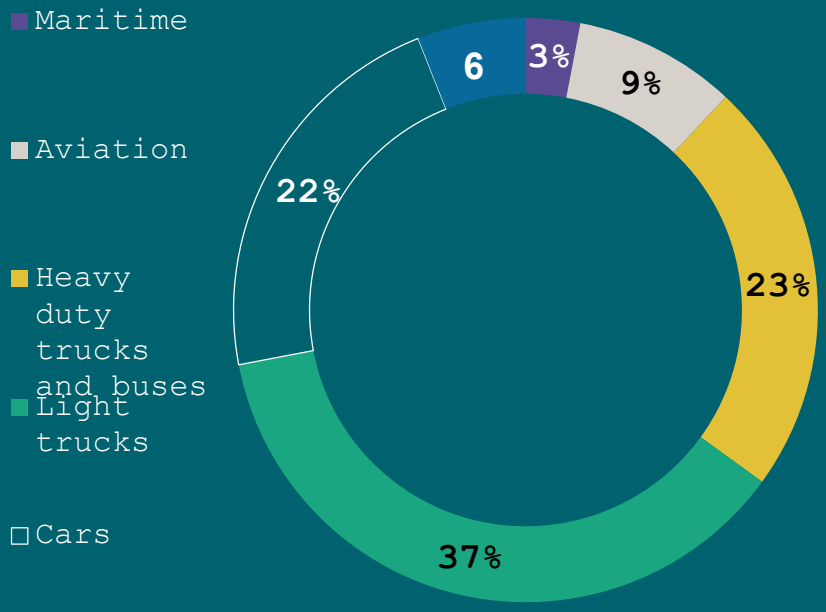
*70,000 Commercial vehicle globally with Hexagon energy storage solutions*

# Transportation sector is the highest emitter of GHG in North Ame




Sources of Greenhouse Gas Emissions | US EPA

# Breaking down the transport sector $CO_2$ emission contributors

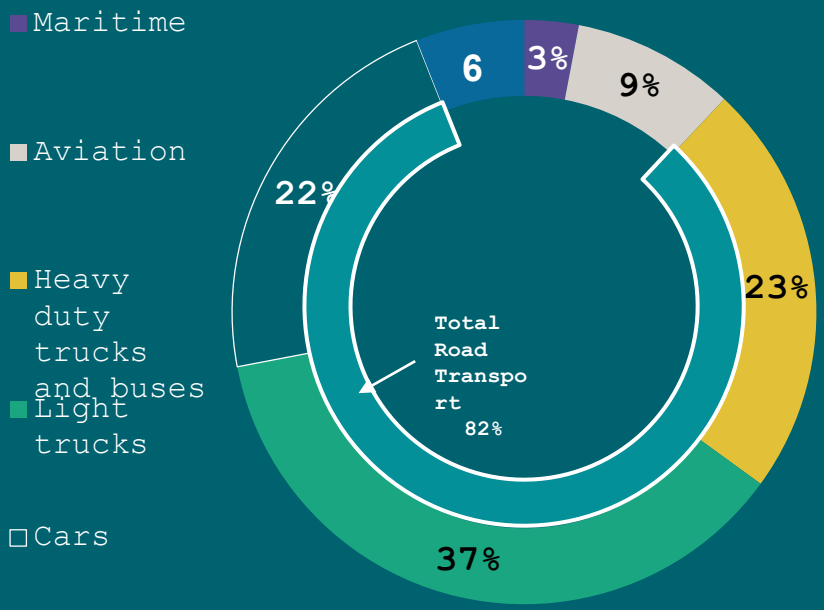



Source: EPA.gov



HEXAGON AGILITY

# Road transport comprises 82% of total transport emissions

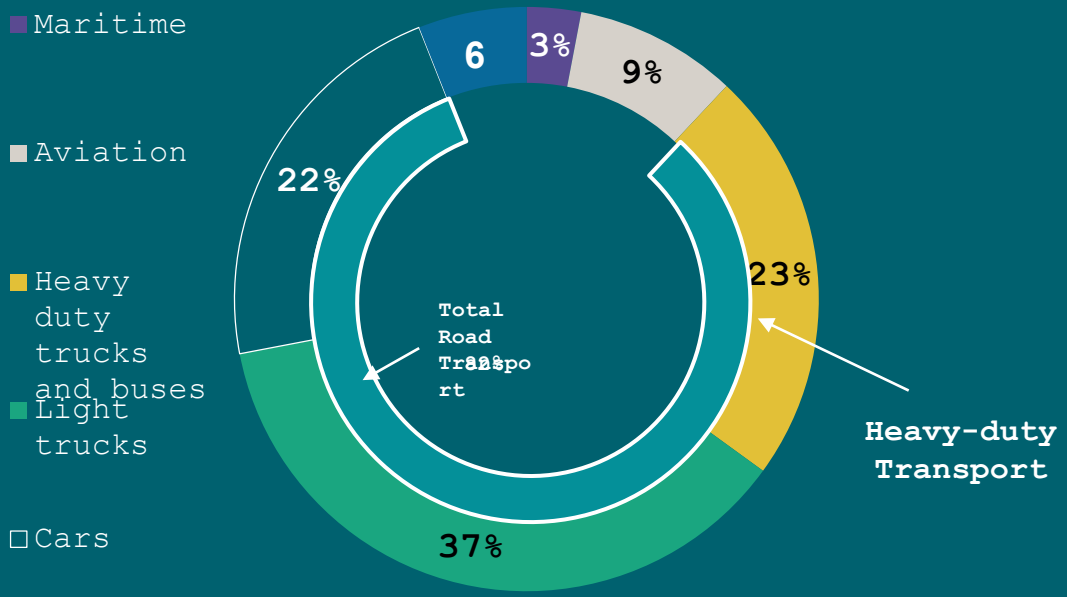


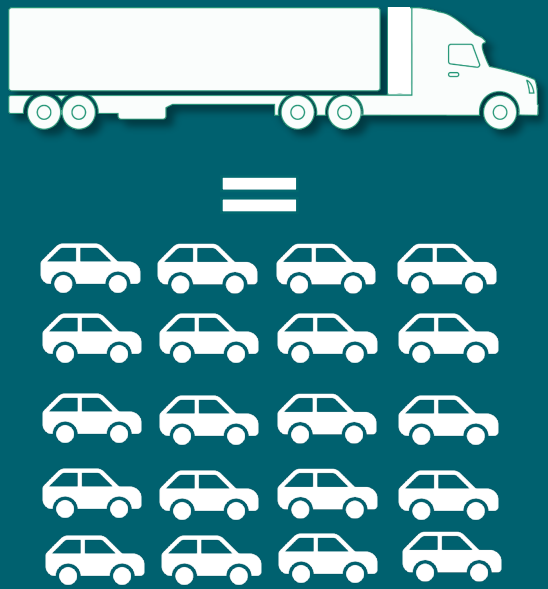

Source: EPA.gov



HEXAGON AGILITY

# On a per vehicle basis HD trucks are the highest emitters



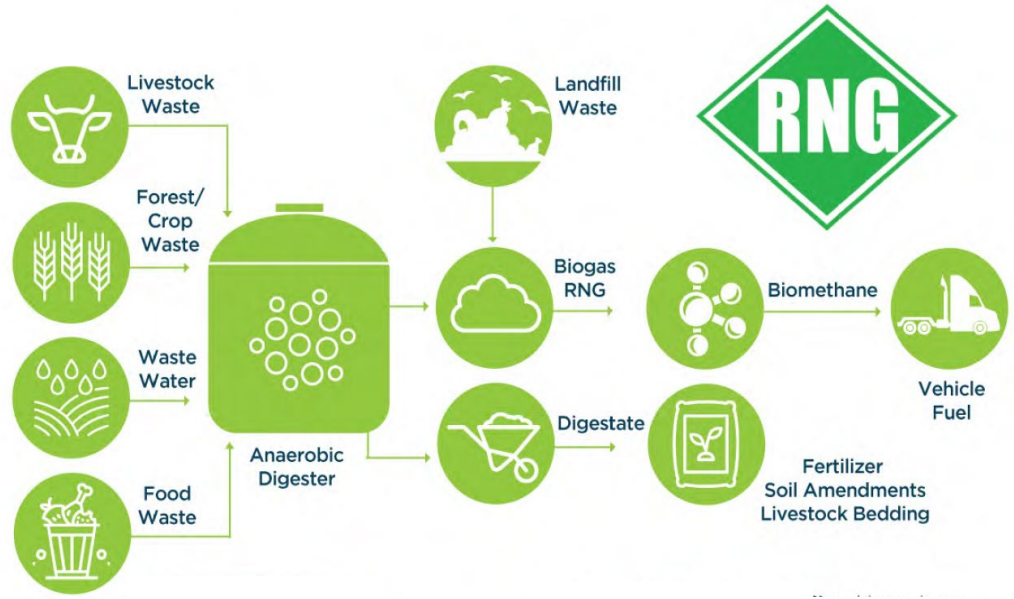
Trucks are high emitters of GHG
1 truck equivalent to 20 cars

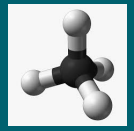
Source: EPA.gov



HEXAGON AGILITY

# How is waste converted to RNG?



Production of RNG involves the capture of methane from escaping into atmosphere

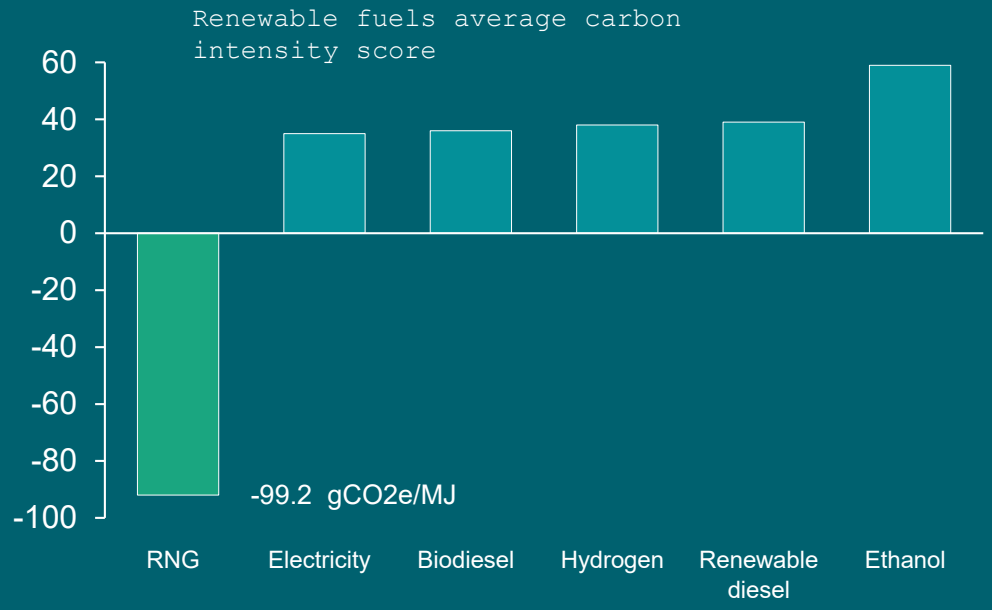
RNG and geologic natural gas can be blended at any mix ratio without impact in performance but with reduction in pure RNG CI score

Natural gas transport vehicles can run RNG, geologic natural gas or blended gas without modification



HEXAGON

# RNG is the only carbon negative clean energy solution that is available today




Diesel 100

*Carbon intensity can be defined as a fuel's lifecycle, or well-to-wheel, greenhouse gas emissions per unit of transportation energy delivered. It's important to note that a CI score accounts for lifecycle emissions, not just those that are emitted when a fuel is used by the transportation sector.*

Source: California Air Resources Board LCFS Quarterly data summary 1/31/23



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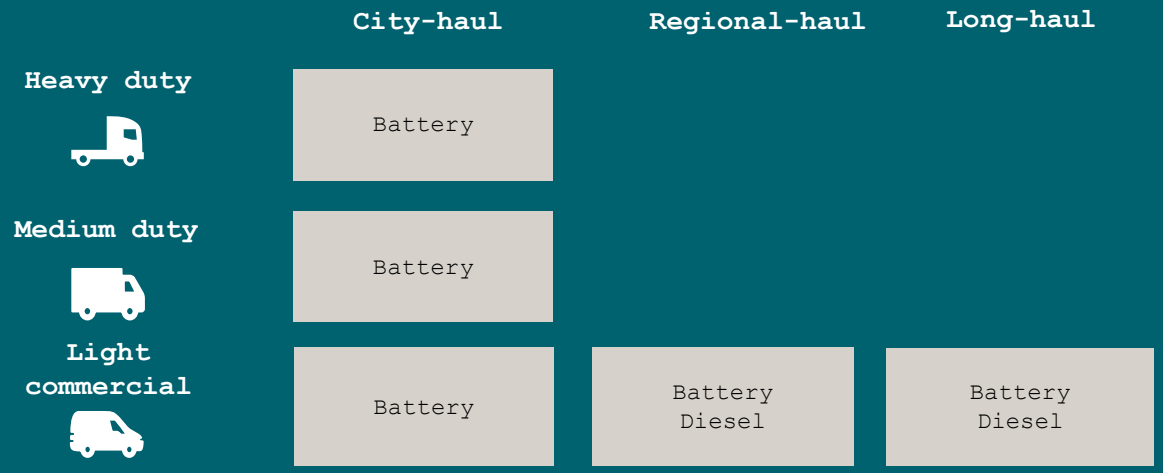
# We believe there will be multiple clean energy solutions required to meet the 2030 emission reduction targets

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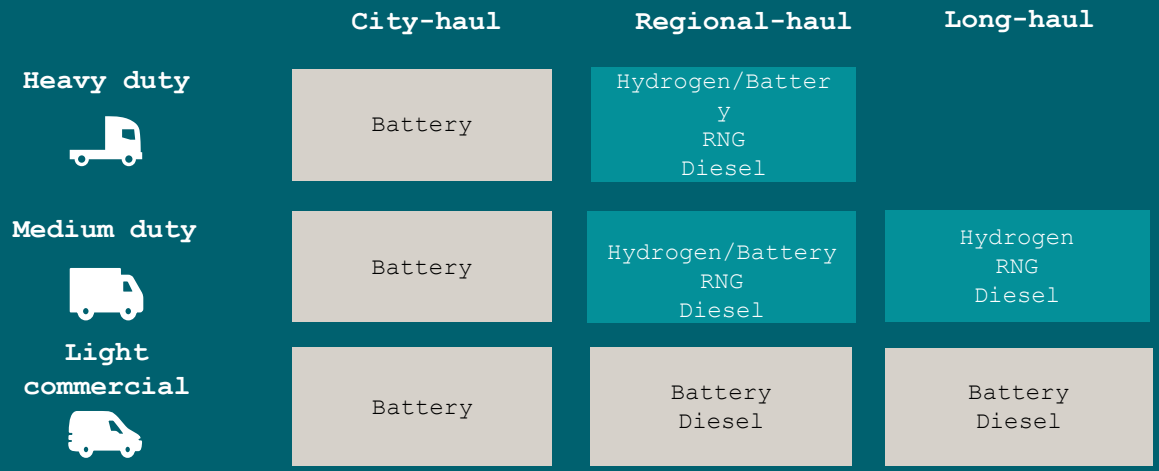
# As payloads increase and longer routes are required clean energy solutions with higher energy density are required




Use case split by segment

Niche market position for ICE-RNG

Key market position for ICE-RNG

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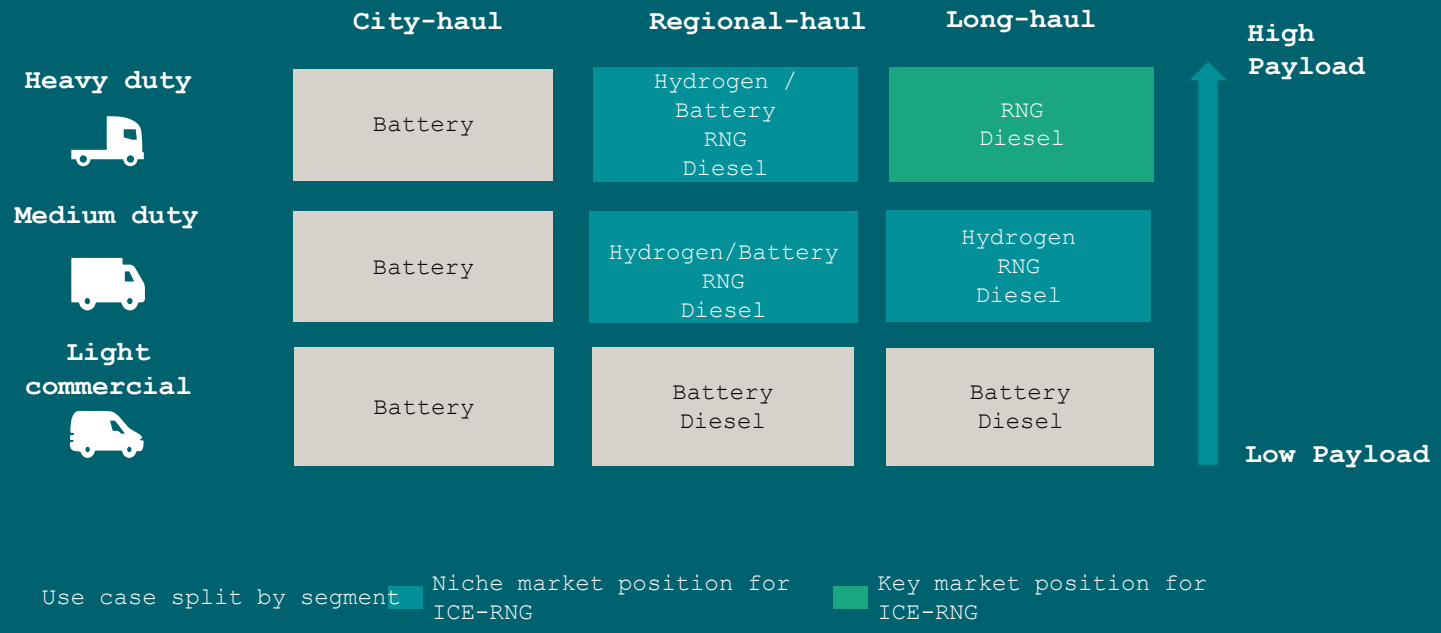
# Today and for the foreseeable future RNG is the best clean energy solution for class 8 HD long haul trucking

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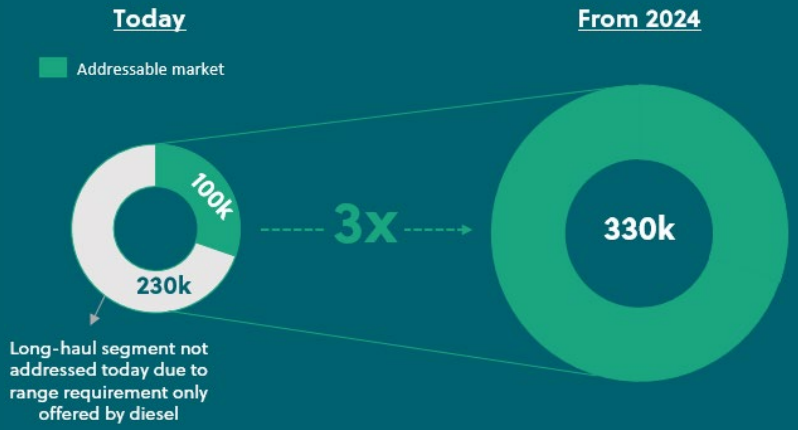
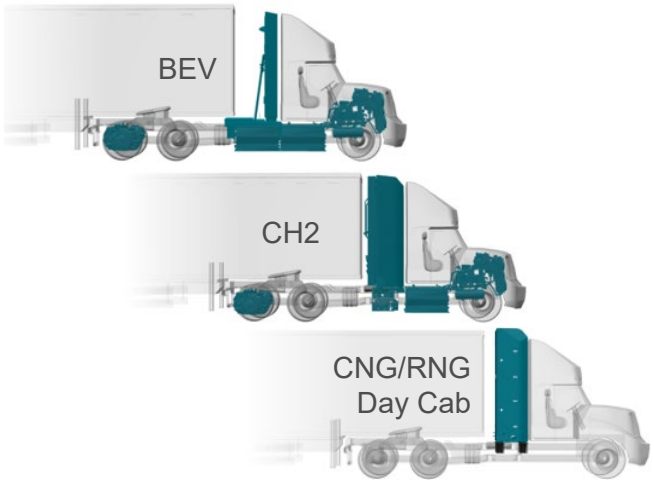
# The Game Changer

## Cummins X15N engine to be launched in 2024

**US heavy-duty truck addressable market for natural gas solutions**
(# trucks sold per year)




# Technology readiness coupled with operational feasibility limiting truly viable solutions for HD long-haul trucking

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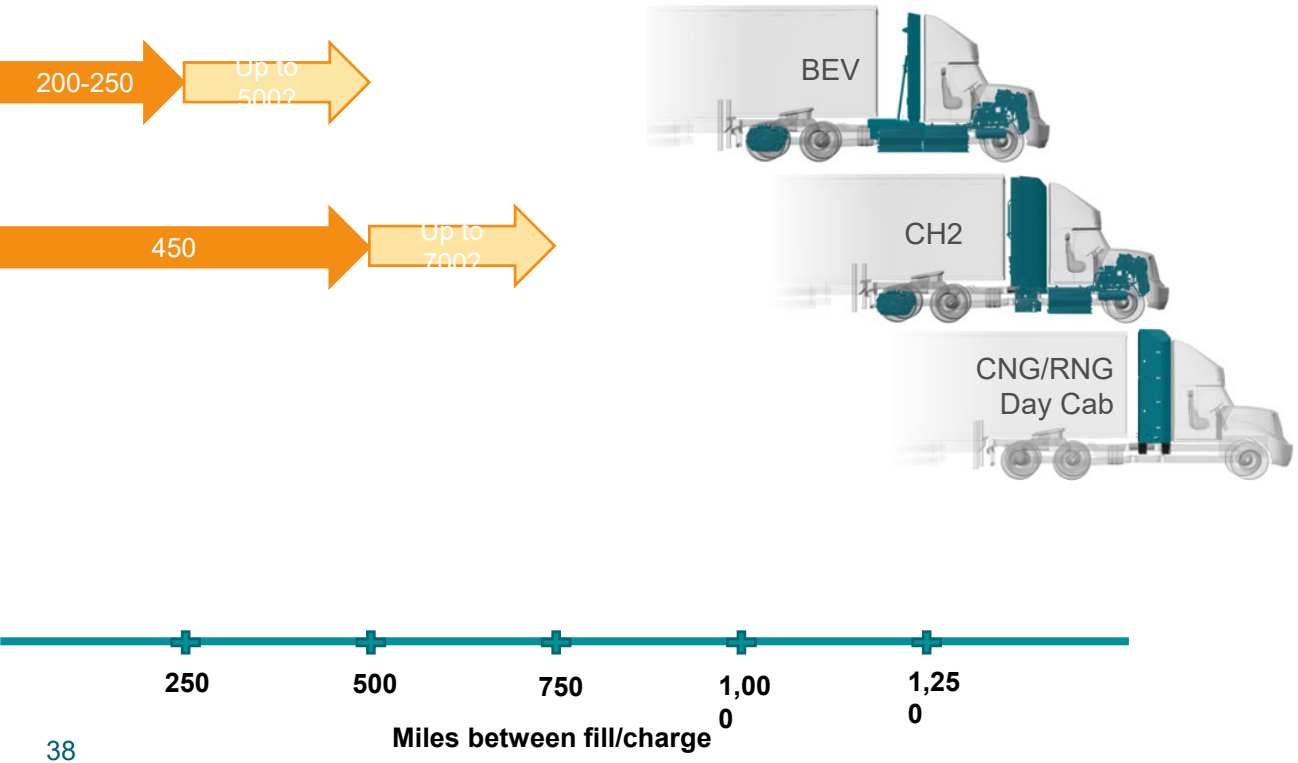
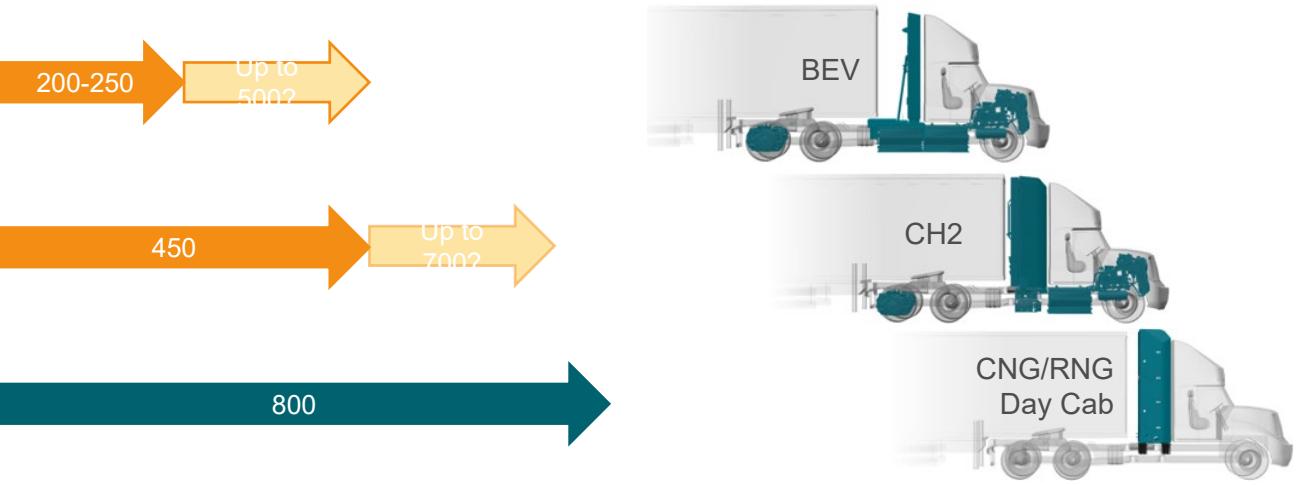


# Only one alternative fuel solution today allows heavy-duty long-haul fleets to adopt at scale and still meet fleet operational demands - RNG



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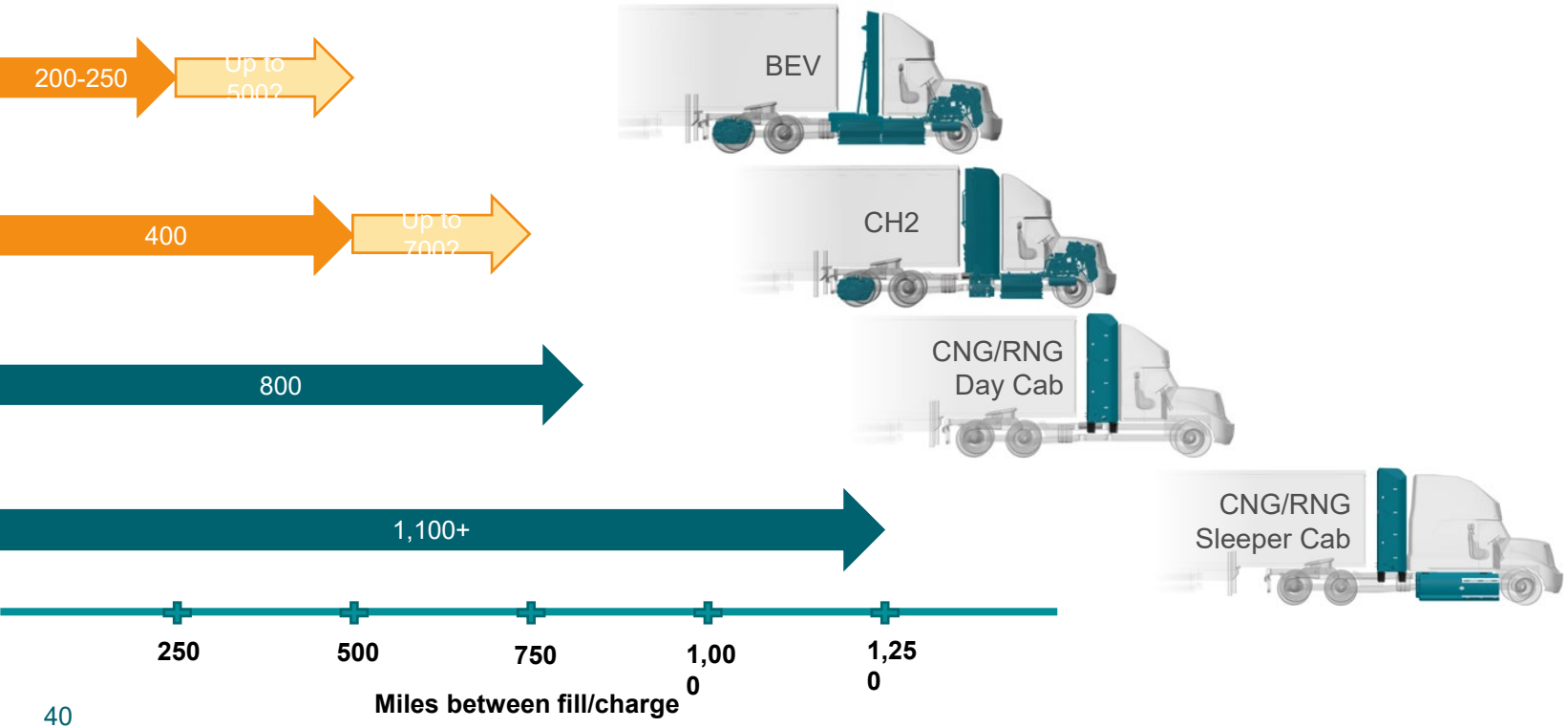
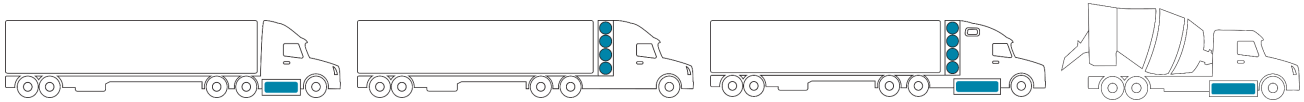
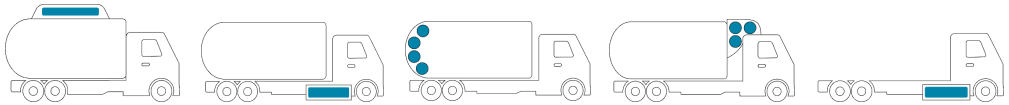
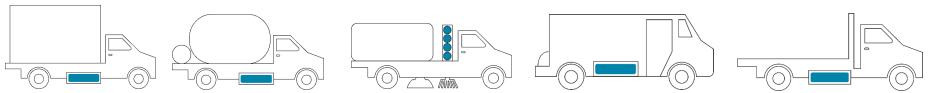


# Natural gas vehicle offerings mature and poised to capture larger portion of hardest to solve segment – high payload and long-haul trucking

| | |
|---|---|
| Heavy Duty Truck |  |
| Refuse |  |
| Bus & Coach |  |
| Medium Duty |  |

Notable OEMs

Source: Hexagon

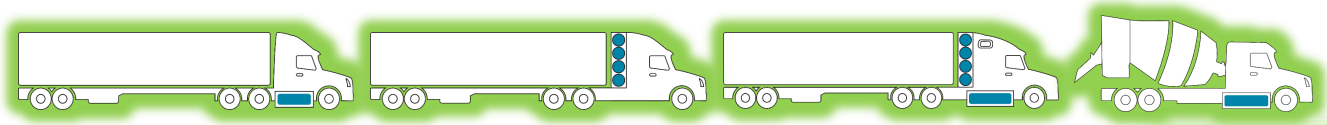
# RNG for North American HD Truck and Refuse well-positioned indefinitely into future

Heavy Duty Truck

Refuse

Bus & Coach

Medium Duty



Applications well suited for CNG today and into the future

Applications well suited for BEV today and possibly H2 solutions in future

SCANIA FREIGHTLINER KENWORTH Peterbilt MACK ELDORADO REV GROUP VOLVO NEW FLYER OF AMERICA

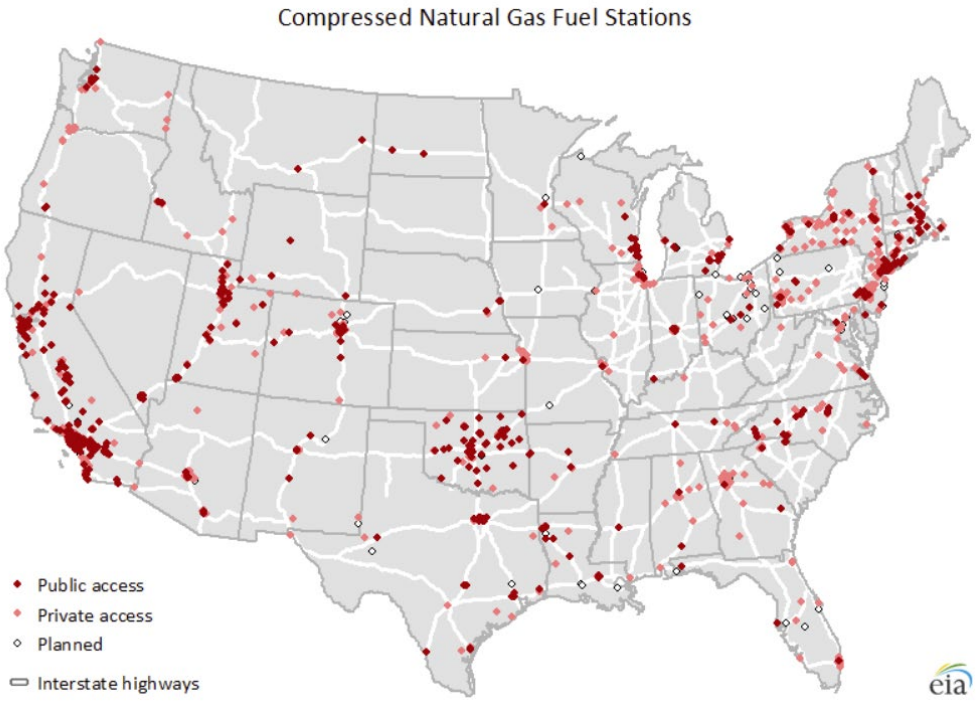
Notable OEMs

Source: Hexagon



HEXAGON AGILITY

# RNG/CNG fueling infrastructure is already in place along key transport routes in the US supporting long-haul transport




**1,680**
CNG stations in the US today

**50**
planned

**Over 69%**
Natural gas used in transportation is RNG



U.S. Energy Information Administration - EIA - Independent Statistics and Analysis

# RNG is the only alternative fuel that is immediately deployable at scale

| | | |
|---|---|---|
| **Highest carbon abatement potential** | -99.2 g/CO2/MJ | Lowest Carbon Intensity score as calculated by CARB of any fuel alternative for HD transport |
| **Best performing energy choice for fleets** | 1,100 + | Mile range potential for HD transport between fill with no loss of payload |
| **Available fuel and filling stations** | 1600+ | Public and private HD CNG filling stations available in North America |
| **Mature technology with OEM support** | 100+ | OEM Natural Gas vehicle platforms available globally with over 60 in North America |
| | 15+ | Global OEMs with mature offerings in CNG/LNG/RNG, incl. DTNA, MACK, Volvo, Kenworth, Peterbilt and many more |
| **Positive TCO for today's HD fleet** | 1st | Available renewable fuel, mature product platforms, OEM support and an operating model that allows for fleet efficiency make RNG the best alternative fuel solution |

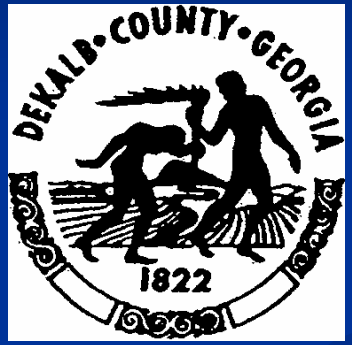
Source: Third party consultant



HEXAGON AGILITY


Clean air everywhere

# DeKalb County




# AFV Initiatives

NAFA 100 BEST FLEETS

NAFA GREEN FLEET AWARDS

# Fleet Management

- 152 Positions 138 Filled
- $33 million Annual Operating Budget
- $40 million Annual Vehicle Replacement
- Fleet averages 30,000,000 miles Annually
- Fleet Management maintains 3622 Vehicles
- 437 Alternative Fuel Vehicles 12%


DeKalb County
Public Works
Fleet Management
5350

# CNG/ Propane/ Electric

- 262 CNG Heavy Duty/ 49 on order
- 73 CNG Light Duty
- 78 Propane Light Duty
- 37 Electric/ 35 on order 48 scheduled to order this year

# CNG Powered Vehicle types in our Fleet

## Heavy Duty / Medium Duty

- Rear Loaders
- Front Loaders
- Side Loaders
- Automated Side Loaders
- Roll Off Trucks
- Grappler Trucks
- Crew Trucks
- Crane Trucks
- Level Lift Trucks
- Bucket Truck
- Road Tractors
- Road Fork Trucks

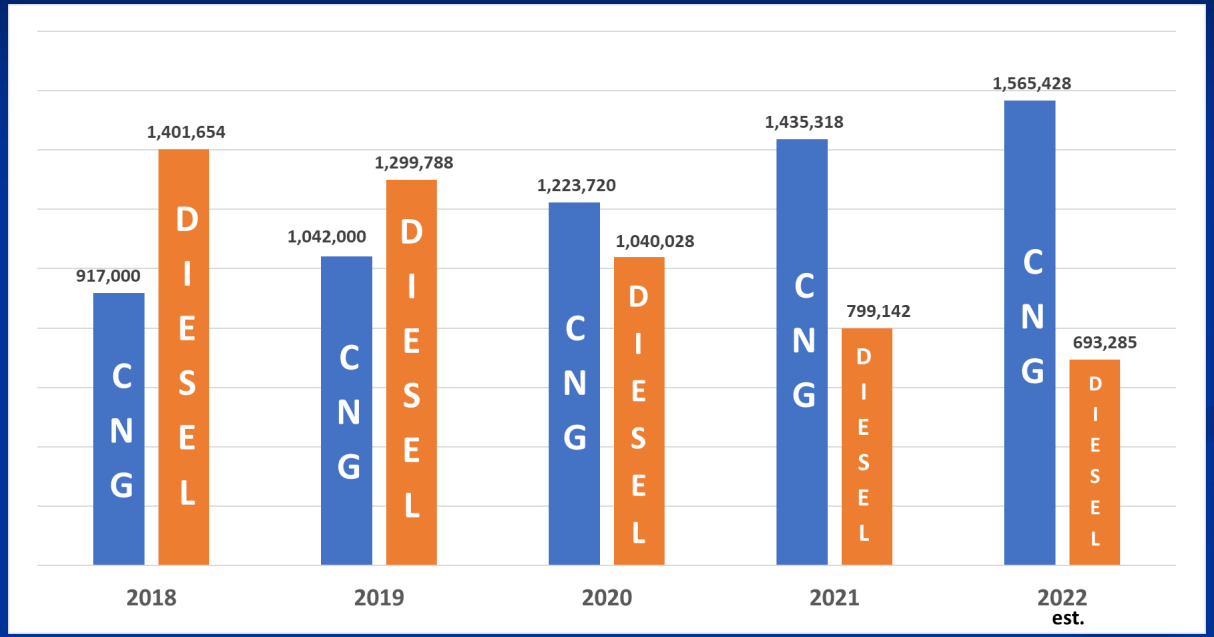
## Light Duty

- Pickup Trucks
- Sedans
- Vans
- Missed Collections Trucks

# CNG Engines

- Cummins Westport
  - 8.9 Liter and 11.9 Liter
  - Soon X10 and X15
- Ford
  - 5.0 Liter
  - 3.7 Liter
- Isuzu
  - 5.7 Liter (GM)
- Navistar
  - 7.6 Liter (Phoenix)

# Fuel Usage (in gallons)



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**DeKalb County Fleet Management**

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