Green House Gas Reduction Potential Pathway

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Reducing CO2 Footprint

Low Carbon Fuels

Hybrids

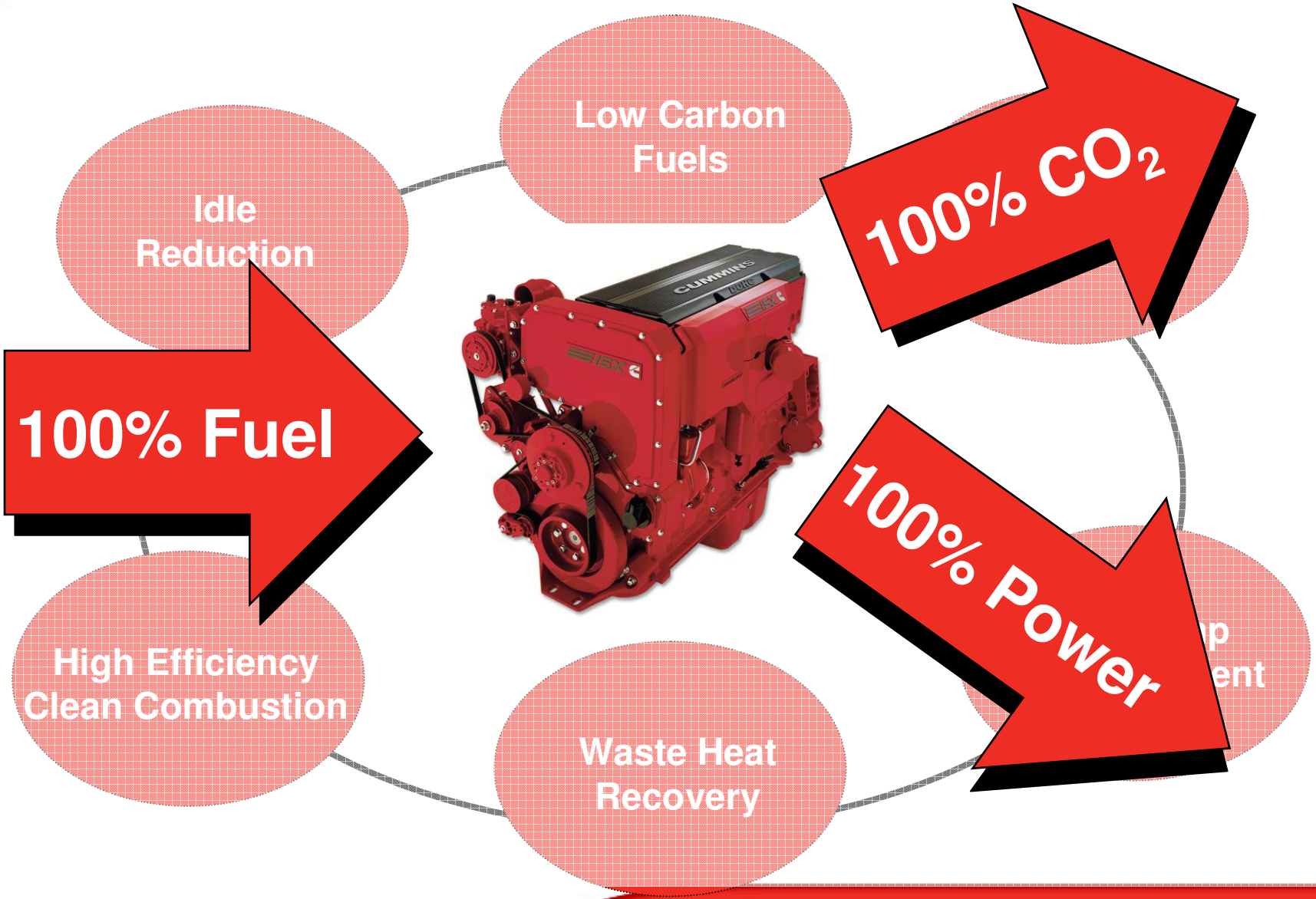
Low Temp Aftertreatment

Waste Heat Recovery

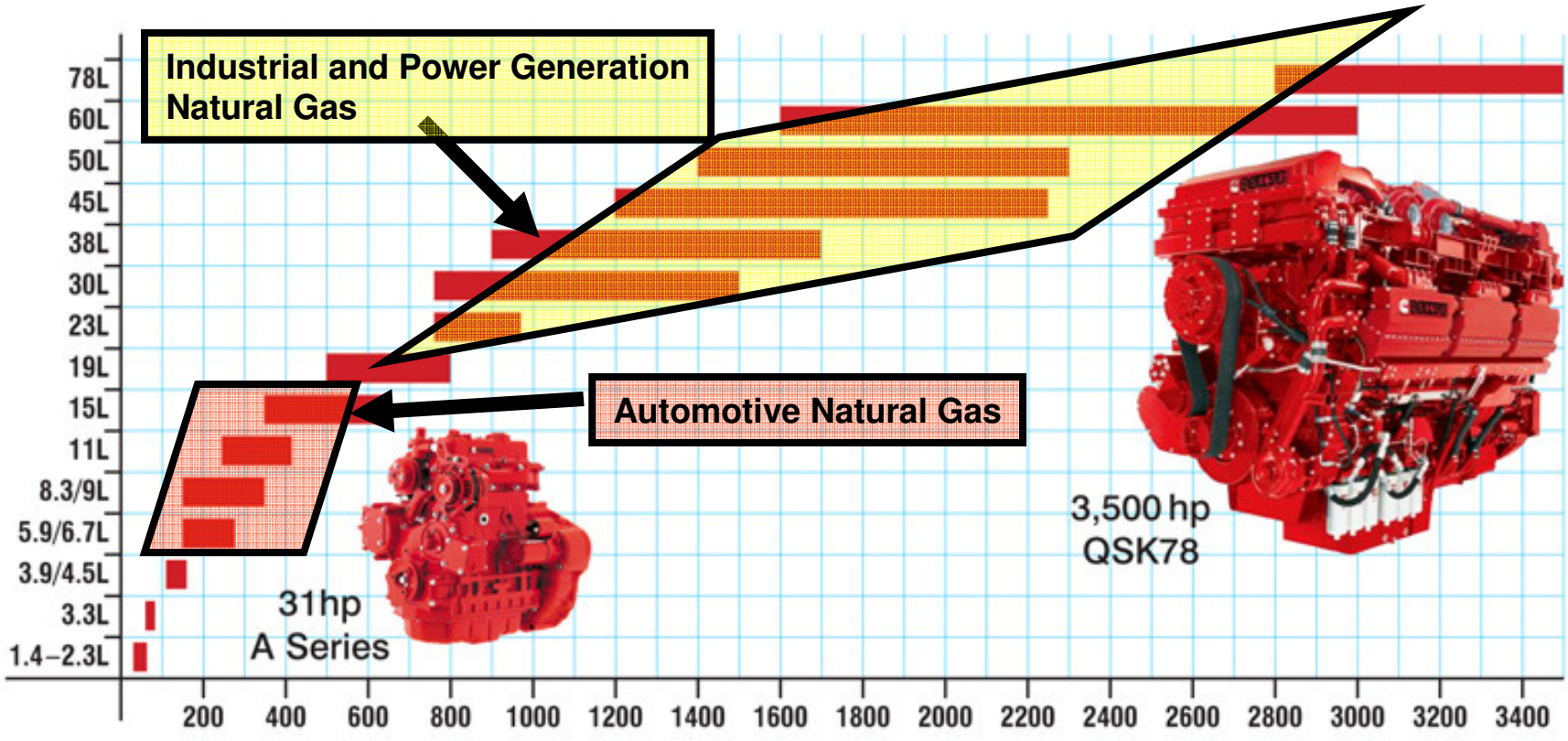
High Efficiency Clean Combustion

Idle Reduction

Reducing CO2 Footprint

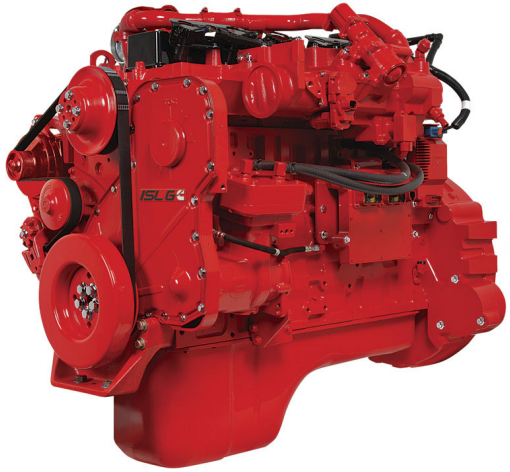


Cummins Engines
31 to 3,500 HP

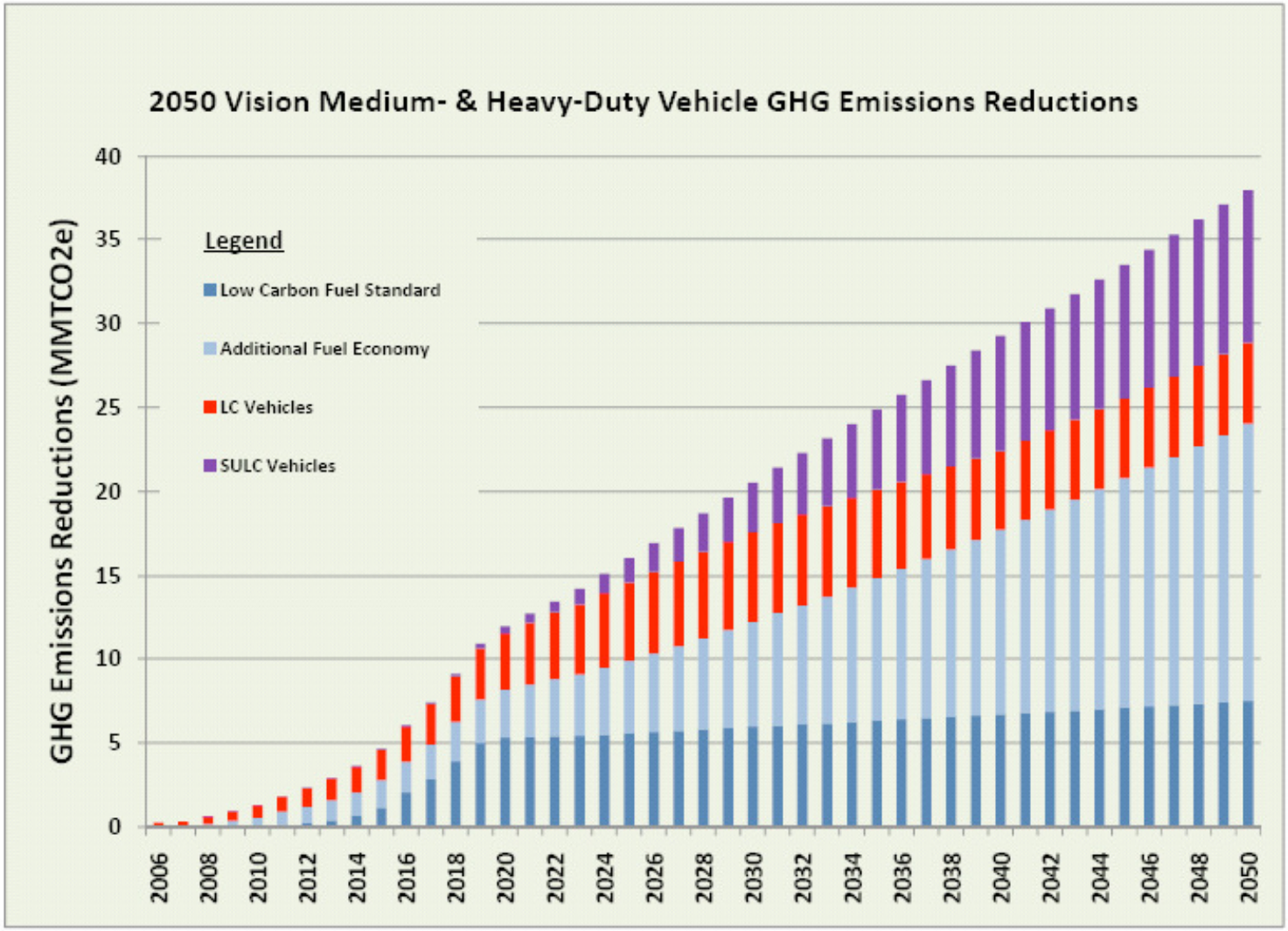


Lower Carbon Fuel Engines

- Low carbon fuels: natural gas, ethanol, butanol, biodiesel etc
- Renewable
- Cummins experience with on road natural gas engines for over two decades
- ISLG met 2010 emissions three years early – SI engines
- California important market



GHG Reduction – CEC Estimate



Medium and Heavy duty GHG Emissions Reductions (2009 to 2020) - CEC

Category	GHG Reduction ($MMTCO_2e$)	Percent GHG Emissions Reduction
Low Carbon Vehicles	22	53%
Super UL carbon Vehicles	1	2%
Fuel Economy Improvements	19	45%
Total Reductions	42	100%

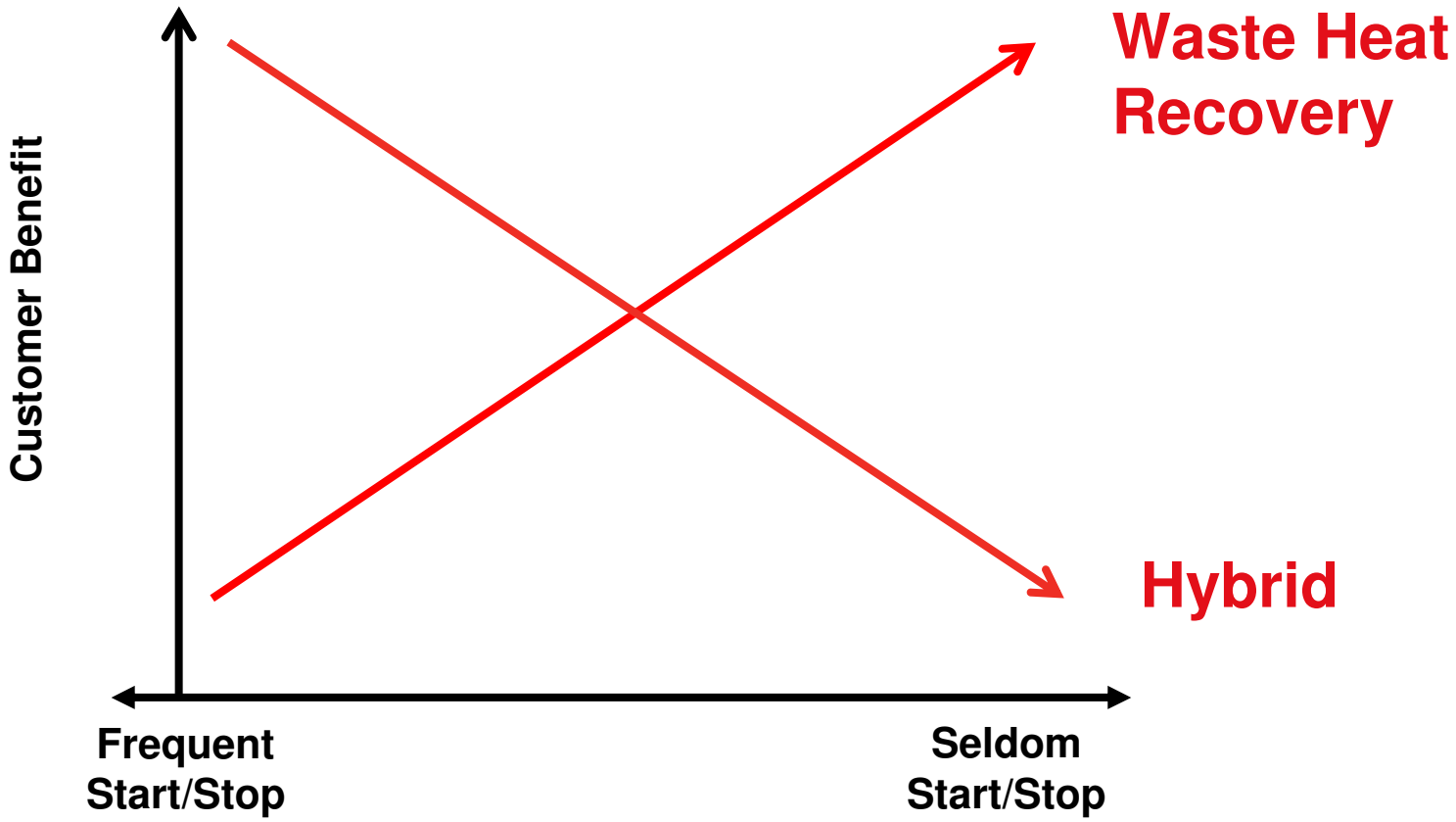
GHG Reduction potential

- Low carbon fuels
  - E85 lowers GHG more significantly
  - Natural gas engines experience
  - Fuel change practical
- Engine down size
  - Reduce engine fuel consumption
  - Integrate with engine electrification
  - Reduce criteria pollutants and GHG
- Hybridize
  - Energy recovery
  - Technologies /products available
  - Product cost is an impediment for commercial vehicles

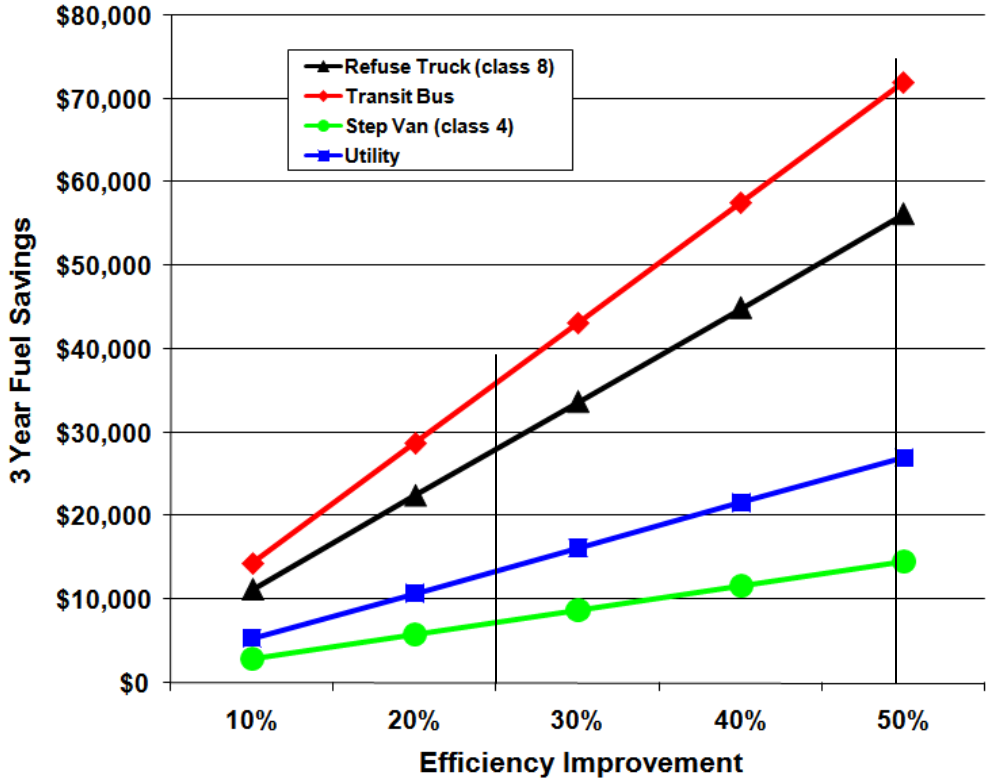
E85 Engine Attributes Relative to Diesel

- Diesel-equivalent peak torque and brake thermal efficiency
- Lower GHG - as much as 60%
- Engine system less costly & easy to package
- Higher power density potential – lower cylinder pressure requirements than diesel
- Down sized diesel engine maintains diesel-like robustness

Waste Heat Recovery vs. Hybrid



Hybrid Fuel Savings vs Efficiency Improvements



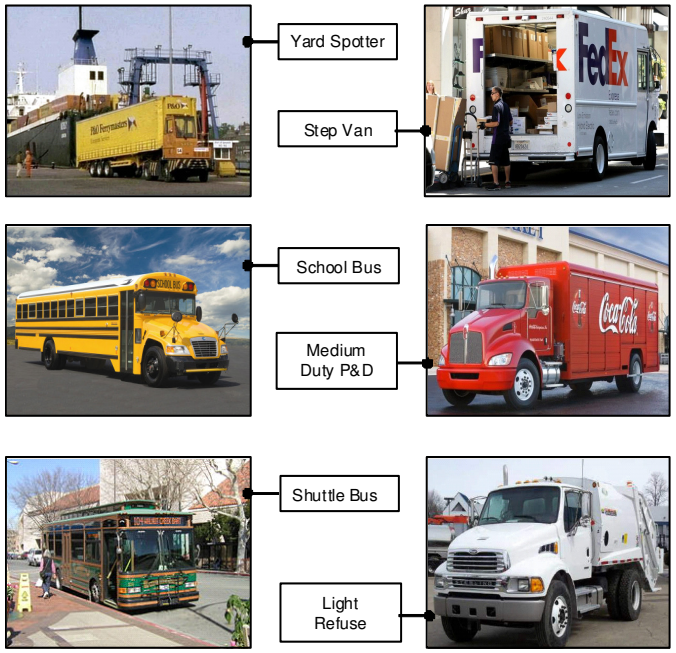
Significant Benefit of Engine Centric Power Train

Ethanol Engine/Hybrid Potential

- Demonstrate a combined engine / hybrid 80% reduction in petroleum based fuels over a drive cycle
- Demonstrate a combined engine / hybrid 70% reduction in CO2 emissions over a drive cycle
- Demonstrate a combined engine / hybrid 36% reduction in energy use over a drive cycle

Potential Markets

E85 Engine Integrated with Hybrid System
(Hybrid System could also be integrated with a Natural Gas or Clean Diesel Engine)

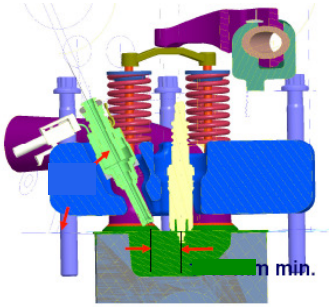


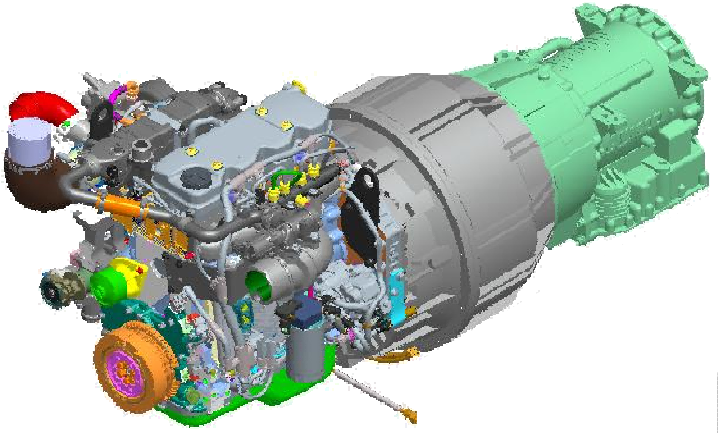
- Vocational Trucks
  - Bucket
  - Dump
- Other applications
  - Pick up & delivery
  - Shuttle bus
- Based on the relationships of Cummins and its California Distributors, we believe the following sectors will have an interest in participating in a prototype demonstration: beverage delivery; municipal government, public and private utilities, irrigation districts, and transit fleets.

Next Steps

- CMI Natural Gas engines are ready now for a demonstration project in a hybrid vehicle
  - CMI is interested in integrating a hybrid power train with a CMI natural gas engine

- CMI is interested in developing diesel engines for ethanol fuel
  - Greater GHG reduction than natural gas
  - Improved hybrid technology
  - Appropriate for CNG





Summary

- Low carbon fuel combustion technologies available for medium and heavy duty engines

- Engine down size
  - Reduce engine fuel consumption
  - Integrate with engine electrification
  - Reduce criteria pollutants and GHG

- Hybridize
  - Energy recovery
  - Technologies /products available-improved systems on the horizon

- CMI strongly positioned to support Natural Gas and Ethanol demonstration projects in a hybrid vehicle