Reducing Heavy-Duty Long Haul Combination Truck GHG Emissions and Fuel Consumption

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Who are NESCCAF and ICCT?

- NESCCAF stands for Northeast States Center for a Clean Air Future. NESCCAF's goal: create solutions to air pollution issues through scientific research, policy analysis, and outreach.
- NESCCAF's sister organization is NESCAUM - A nonprofit founded in 1967 by the New England governors
- ICCT stands for the International Council on Clean Transportation (ICCT). ICCT's goal is to dramatically reduce conventional pollutant and greenhouse gas emissions from transportation sources to improve air quality, human health, and the environment.
- The Council is made up of leading regulators and experts from major motorized countries around the world that participate in ICCT activities since 2001

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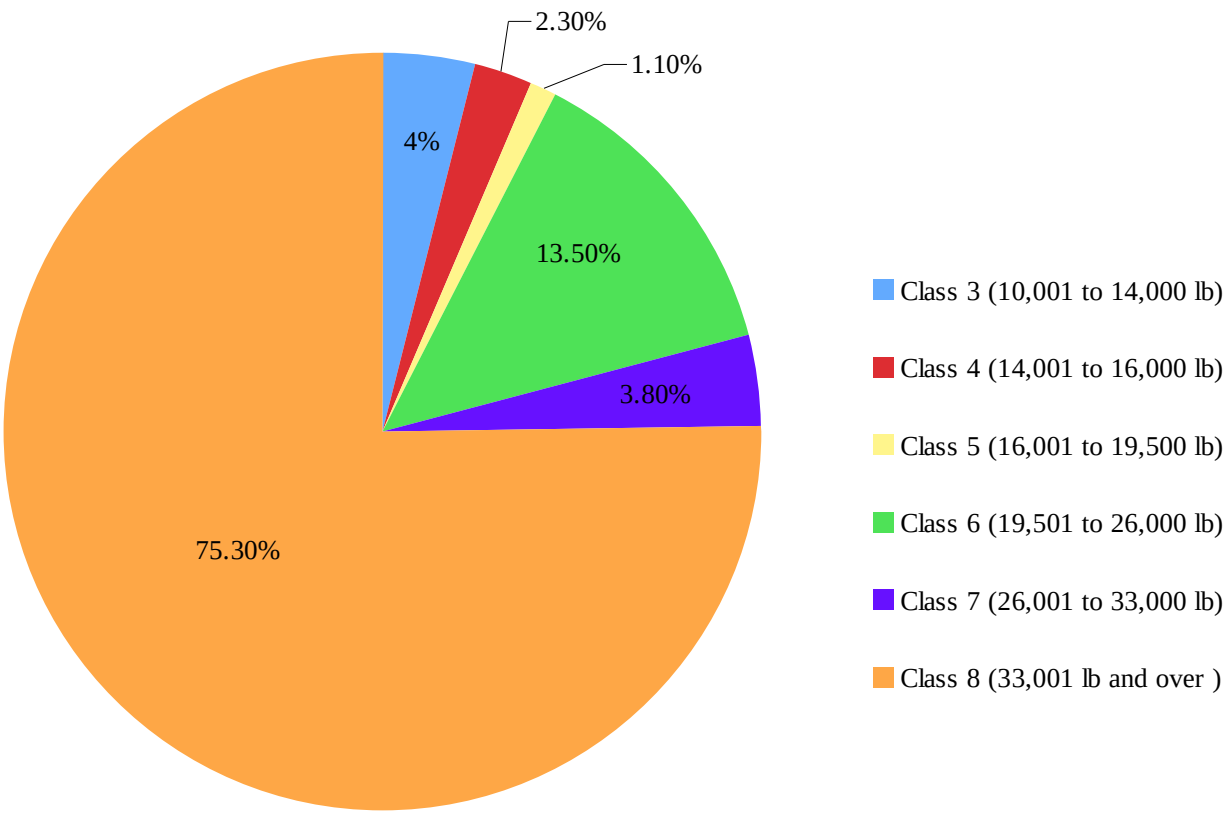
Fuel Consumption by Medium and Heavy-Duty Vehicle Class



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Study Goals

- Build on substantial work being done by the U.S. government, fleets, and national labs
- Simulate improvements in fuel economy and emissions from combined engine, transmission, and vehicle technologies
- Estimate technical feasibility of reducing HD fuel consumption and emissions
- Provide cost estimates for different combinations of technologies
- Estimate fuel that could be saved with widespread introduction of technologies

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Research Steering Committee

- Engine manufacturers
- Vehicle manufacturers
- State and federal agencies
- Fleets
- Non profits and environmental groups
- Suppliers
- Developers of new HD technologies

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Technical Approach

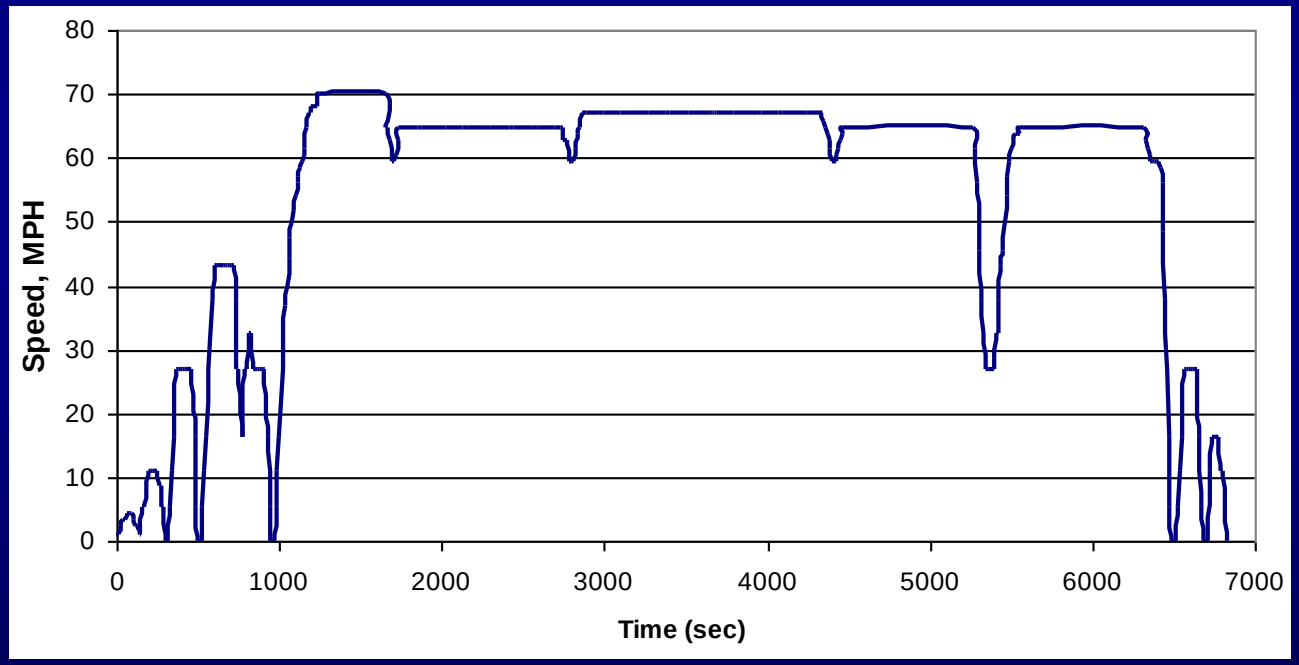
- Engine and vehicle simulation modeling using RAPTOR and GT-Drive
- Cost analysis relied on published information, and conversations with suppliers and OEMs
- Cost benefit analysis assumed 7% discount rate, $2.50 and $3.53/gallon of diesel, 3 year and 15 year vehicle life
- Fleet GHG and fuel consumption reductions estimated using a fleet model developed by TIAX, LLC
- Contractors:
  - SwRI for engine and vehicle simulation models
  - TIAX for cost analysis and cost/benefit calculations

Technical Approach (continued)

- Select baseline vehicle representative of the current population
  - KW T-600 tractor with standard 53’ van trailer
  - Cd = 0.63, Crr = 0.0068
- Select baseline engine representative of the current population
  - Volvo D13, 485 HP @ 1900 RPM
- Create a list of fuel saving technologies and, using available information, select a shorter list of technologies to simulate

Duty Cycle

- A duty cycle including grade was selected for evaluation of the technologies
  - Meant to simulate long haul operation



Technologies Modeled with Standard Trailer

- Baseline vehicle
- variable valve actuation
- Advanced exhaust gas recirculation
- Mechanical turbocompound
- Slower road speed (60 mph)
- Electrical turbocompound
- Parallel hybrid system
- Bottoming cycle
- Improved aerodynamics and tires
- Advanced aerodynamics and tires
- Hybrid, bottoming cycle, and slower road speed

Turbocompounding and Bottoming Cycle

- Mechanical turbocompound
  - Power turbine geared directly to the crankshaft
    - Power turbine and crank speeds are tied together
  - Overrunning clutch to prevent BSFC loss at light load
- Electric turbocompound
  - Power turbine drives an electrical generator
    - Power turbine and crank speeds are independent
  - Electric power used to drive a motor connected to the transmission
    - Can be stand-alone or part of a hybrid system
- Bottoming Cycle
  - Utilize waste heat from the engine to produce additional power with a steam turbine
  - Four system configurations were evaluated
    - Engine coolant based system, EGR based system, EGR supplemented by exhaust heat up to EGR cooler outlet temp., EGR and full exhaust heat
  - EGR and full exhaust heat performed the best
    - About twice the power of EGR only, and much better than EGR supplemented by exhaust heat
    - Requires a secondary EGR cooler

Technologies Modeled with Longer and Heavier Trailer

- Longer and heavier trailer alone (Rocky Mountain Double) and advanced aerodynamics and tires
- Longer and heavier trailer with electrical turbocompound, hybrid, advanced aerodynamics and tires
- Longer and heavier trailer with bottoming cycle, hybrid, 60 mph, advanced aerodynamics and tires

Results

Package Name	Fuel Consumption/ CO2 Reduction (%)	Incremental Vehicle Cost ($)[a]	Lifetime Cost of Ownership (15 years, 7%) [a]	Time to Payback[a] (Years)
Baseline	n/a	n/a	n/a	n/a
Building Block Technologies				
SmartWay 2007 (SW1)	17.8%	$22,930	-$23,600	3.1
Advanced SmartWay (SW2)	27.9%[2]	$44,730	-$55,800	3.8
Parallel hybrid-electric powertrain (HEV)	10%	$23,000	$100	7
Mechanical turbocompound	3.0%	$2,650	-$5,500	2.0
Electric Turbocompound	4.5%	$6,650	-$5,500	3.5
Variable Valve Actuation (VVA)	1.0%	$300	-$2,500	0.6
Bottoming cycle	8.0%	$15,100	-$4,800	5.2
Advanced EGR	1.2%	$750	-$2,600	1.4
Operational Measures				
Rocky Mountain Double (RMD) trailers - 48’ + 28’ Trailers	16.1% (grossed out) 21.2% (cubed out)	$17,500	-$34,100	2.1
60 mph speed limit	5.0%	$0	-$13,900	n/a

Results

Package Name	Fuel Consumption/ CO2 Reduction (%)	Incremental Vehicle Cost ($)[a]	Lifetime Cost of Ownership (15 years, 7%) [a]	Time to Payback [a] (Years)
Maximum Reduction Combination Packages				
Maximum reduction combination 1 (standard 53' trailer, hybrid, BC, SW2, 60 mph)	38.6% (grossed out) 40.2% (cubed out)[6]	$71,630	-$27,300[5]	4.8
Maximum reduction combination 2 (RMD, hybrid, el. turbocompound, VVA, SW2, 60 mph)	48.7% (grossed out)[6] 46.2% (cubed out)[6]	$80,380	-$41,600[5]	4.3
Maximum reduction combination 3 (RMD, BC, hybrid, SW2, 60 mph)	50.6% (grossed out)[6] 48.3% (cubed out)[6]	$89,130	-$37,200[5]	4.7

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Results

- Notes for the table:

[1] Includes idle reduction benefits from a diesel-fired APU

[2] Includes idle reduction benefits from battery storage; the modeled on-road fuel consumption improvement was 5.6%

[3] Includes credit for an auxiliary power unit (APU), which is included in the SmartWay package, but is not needed in a hybrid vehicle.

[4] The lifetime cost of ownership figures are calculated using fuel savings averaged between grossed out and cubed out trucks.

[5] Includes idle reduction benefits from battery storage

[a] Calculations based on year 2022 high volume technology costs, EIA 2022 fuel price ($2.50/gal), a 7% discounted cash flow; time to payback assumes a constant 120,000 miles per year; the cost of ownership calculation assumes annual mileage declines over the life of the vehicle with a total mileage of 1.2 million miles in 15 years. Cost based on 3 trailers per tractor.

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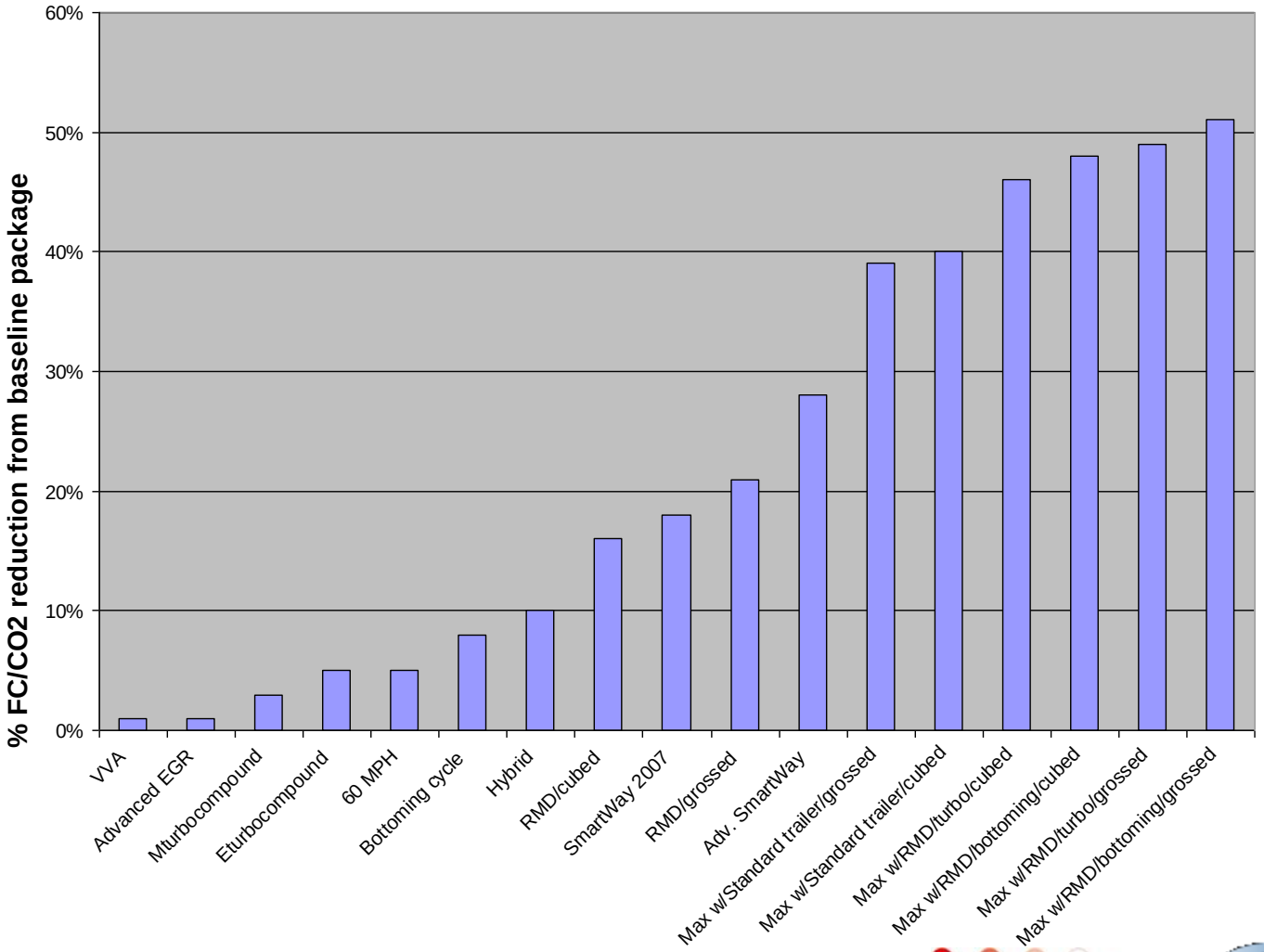
Summary of Findings – Simulation Modeling



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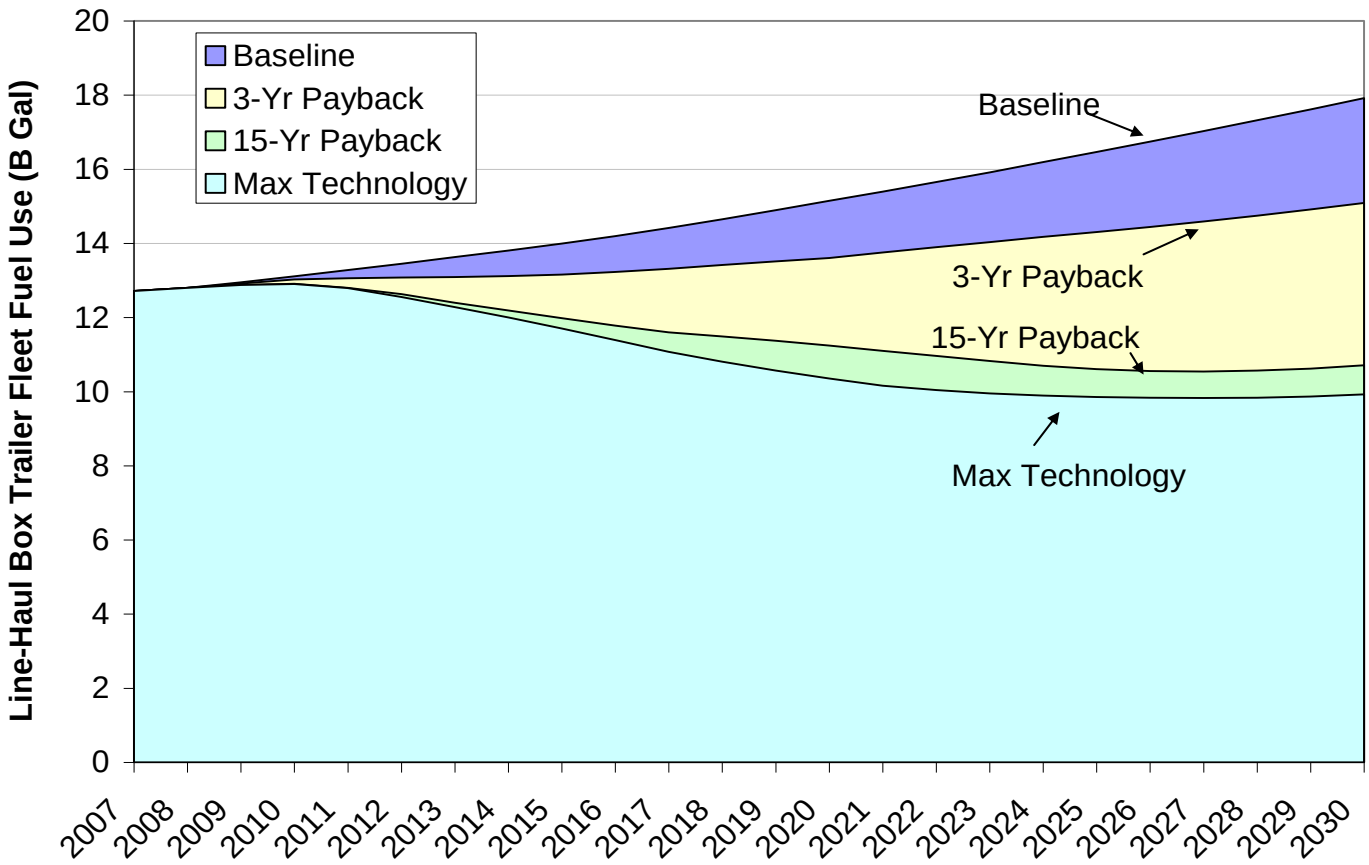
GHG Emissions and Fuel Use Avoided in the U.S. Fleet



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Conclusions

- GHG emissions and fuel consumption can be reduced 1-40% in a standard size heavy-duty long haul truck with the introduction of drivetrain and vehicle technologies, and operational changes
- With changes to tractor length and weight, up to 50% of fuel consumption and GHG emissions can be avoided
- GHG and fuel consumption reductions of up to 50% can be achieved in a cost effective manner assuming a 15 year payback period and a fuel cost of $2.50 per gallon
- To achieve the maximum savings, both vehicle design changes and operational changes will be required. Existing regulations may need to be changed to allow for:
  - road speed governing, longer/heavier trucks, and design flexibility for aerodynamic features.

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Conclusions

- Implementing technologies with ≤ 3-year payback will save over 2 billion gallons per year in the 2030 time frame (12% of "business as usual" consumption)
- Implementing technologies with a ≤ 15-year payback will save 7 billion gallons per year by 2030 (39%)
- Implementing feasible technologies regardless of cost will save 8 billion gallons per year and 88 million tons of CO2 by 2030 (44% reduction)
- Technologies evaluated here are applicable to some degree to other medium and heavy duty truck applications – this is not accounted for in the study results
- Assuming the industry's 18 – 36 month payback requirement, the savings that can be expected will be modest
- Achieving substantially greater reductions will necessitate incentives or regulations that require introduction of fuel saving technologies

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