Commercial Vehicle GHG Reduction

Pathways Initiative Workshop
Pollution Probe
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Retired Volvo Trucks
Commercial Vehicle Market has Huge Variety
Size, Shape, Duty Cycle
Projection – Provided by US DOE in 2009

Projection Oil Consumption by Vehicle Type
Presuming 75% Reduction in Light-Duty Oil Consumption

*Light duty oil consumption reduction from AEO 2007 reference case modeled via increased fuel economy and shifts to flex-fuel, hybrid-electric, and plug-in hybrid-electric vehicles.
Exxon–Mobil “Outlook for Energy” 2016

Transportation – projections

Global transportation demand

- Commercial
- Light-duty road

Transportation demand by region

[Graph depicting transportation demand by region for various years and countries, including OECD32, China, India, Key Growth, Rest.]
The Challenge to Reduce CO2 from Freight

- Light Duty often refers to a 3 legged stool approach to reduced use of fossil energy.
- Heavy Duty Long-Haul - \( \frac{1}{2} \) legged stool???
  - Improving the front (tractor) half of the combination truck through vigorous competition but not much focus on trailers until recently.
  - Minimal government policy plans for low carbon alternate fuels to replace diesel
  - Little government attention to VMT
- We need all three legs.

  Fuel Efficiency
  Engines
  Vehicle
  Truck and tractor
  Implement trailer improvements
  Integrate tractor and trailers for breakthrough aerodynamics.

Policies to enable reduced VMT while still moving the freight that supports our economies.

Serious policies to develop and implement new low carbon fuels for HD application.

A typical size car, operating with the same ton-mpg efficiency as today’s fully loaded tractor trailer rig would get 130 mpg!
## Application Impact on Efficiency Technology

<table>
<thead>
<tr>
<th>Application</th>
<th>Long Haul</th>
<th>Refuse</th>
<th>Utility - Sweeper</th>
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</thead>
<tbody>
<tr>
<td>Approximate Power Demand</td>
<td>Aerodynamics – 50%</td>
<td>Aerodynamics – 10%</td>
<td>Aerodynamics – 0%</td>
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<tr>
<td>Rollings Resistance</td>
<td>Rolling Resistance -30%</td>
<td>Rolling Resistance-20%</td>
<td>Rolling Resistance – 15%</td>
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<tr>
<td>Auxiliary Devices</td>
<td>Auxiliary Devices – 10%</td>
<td>Auxiliary Power – 20%</td>
<td>Auxiliary Power- 85%</td>
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<tr>
<td>Acceleration</td>
<td>Acceleration – 10%</td>
<td>Acceleration – 50%</td>
<td>Acceleration - 0%</td>
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### Applicable Technologies

- Hybrid
- Engine Efficiency
- Waste heat recovery
- Increase load capacity
- Reduced drag
- Hotel anti-idling
- Low Crr Tires
- Powertrain Efficiency
- Mechanism Efficiency
- Vehicle Management
- Hydraulic Efficiency
Projected USA Fuel Use for Heavy Trucks through 2050.

Source: US DOE - GPRA 06 FCVT Heavy Vehicle Benefits

FOCUS On Class 7-8
## Key Technology Areas to Improve Long Haul Truck Freight Efficiency

### Engines
- Diesel Combustion Efficiency
- Waste Heat Recovery
- NOx aftertreatment improvements
- Engine friction reduction
- Engine Auxiliaries (water/oil pump)
- Other New Technology Developments – e.g. all new engine architecture
  - Opposed piston
  - Double compression and expansion

### Truck Technology
- Smart Transmission & Driveline Efficiency
- Powertrain integration (includes engine)
- Cooling optimization
- Vehicle Auxiliaries (Air comp, PS pump, Air Cond, Fan, Alternator)
- Aerodynamics (tractor)
- Weight
- Low Crr Tractor Tires
- Trailer Gap
- Trailer Aero Treatment
- Smart Navigation
  - Autonomous?
- Idle Reduction
- Hybrid (vocational)

### Fleet Operations
- Logistics
  - Load planning
  - Route Planning
  - Backhauls
- Trailers - Tires, Aero, Weight
- Longer Combinations & increased weight (assuming compatible regulations)
- Intermodal (rail)
- Driver Training
- Trailer gap control
- Idle Elimination
- Road speed reduction

Technologies can only contribute to the extent they are integrated into the complete vehicle and system in real applications and are supported by public policy.
US DOE SuperTruck Program

Goals: 50% Increase in Ton-MPG
20% Increase in Engine Efficiency
Demonstrated on highway by 2015

- No Idle Hotel Mode
- Advanced Driver Control
- Waste Heat Recovery Turbo-Compound Efficient Auxiliaries
- High Efficiency Diesel Combustion
- Low Rolling Resistance Tires
- Energy Efficient Lighting
- Improved Tractor Aerodynamics
- Smart Axles
- Improved Trailer Aerodynamics

Hybrid and EV offer potential for urban applications but not on highway.
SuperTruck Aerodynamics

Tractor-trailer integration is key to achieving large drag reduction.

**Based on \( F_{\text{alt\_aero}} \) of 1.12 (from RIA Table 3-19)

Generic sleeper (EPA assumed baseline)

\[ \text{CdA} = 6.3^* \rightarrow \text{BIN III} \]

SuperTruck w/ Phase II trailer

\[ \text{CdA} = 5.43^{**} \rightarrow \text{BIN IV} \]

**Based on \( F_{\text{alt\_aero}} \) of 1.3 [SLF/CFD(0)]

SuperTruck w/ Super-trailer

\[ \text{CdA} = 4.31^{**} \rightarrow \text{BIN VII} \]

SuperTruck tractor with phase 2 trailer vs. Super-trailer suffers >25% drag increase
Topping 10 mpg: Former Trucker of the Year blends driving strategy, equipment

Henry Albert’s Freightliner Cascadia Evolution and Utility 4000 D-X Dry Van feature several standard and cutting-edge fuel-economy components or design elements. Among the notable ones:

- Special windshield for better airflow
- Body-integrated antenna
- Hubcaps at all wheel locations
- Cab extenders with filler piece between the side skirts and the extender body
- Lower front air dam
- Hood-to-bumper filler piece
- Elliptical-shaped mirrors
- Chassis side-fairing enhancements
- ATDynamics TrailerTail
- Wide-base single tires

From Overdrive – November 2013
New Opportunities for Energy Management

• **Momentum Hybrid!**
  - **Intelligent Controls** can leverage ongoing vehicle improvements to achieve further fuel efficiency gains
  - **Auxiliary Integration** can maximize use of free energy
  - **Powertrain Management** minimizes fuel use under given operating conditions
Positive Side effects of vehicle efficiency improvements

- Increased benefit of predictive vehicle controls
- Increased potential for complete vehicle energy management features, e.g. kinetic energy recovery solutions
Trucks haul a lot of air!
Consumer goods and packages usually are low density.
Opportunities for improvements
• Packaging to increase density
• Logistics – load planning and routing

Around 15-20% empty.
Less than 20% exceed 70,000 LBS.
Larger Vehicles Move Freight More Efficiently

- Payload 0.5 Tons, 96 cu-ft, 22 MPG
- Payload 30 Tons, 4000 cu-ft, 6.5 MPG
- Payload 45 Tons, 7300 cu-ft, 5.3 MPG

All numbers are approximate.
Longer Combination Trucks

Single Biggest Potential Efficiency Gain via Lower VMT

Fuel saving for longer US combinations (with volume limited freight - per ATRI study)

Sweden and Finland allowing rigs up to 25.25 m vs 18.75 m in rest of EU (14-20% less fuel)

Quote – Ontario, Canada Ministry of Transport
LCVs are a win-win-win. They are good for the economy, good for the environment and improve highway safety. They can move goods at a lower cost and with fewer greenhouse gas emissions than single-trailer trucks and, under carefully controlled conditions, more safely.
Port Truck In Sweden
Increase Intermodal Truck-Rail

Estimated Fuel savings of around 50% but need better study.
CO2 Reduction through Bio-fuels?

• Renewable fuel alternatives are possible
• But many arguments about GHG efficacy and impact on food supply.
• Significant GHG reductions are possible, for some paths
  • But limited feedstock and high cost
Long-Term Vision Needed

- Long Haul
  - Truck only lanes
  - Autonomous operation
  - Lower speeds
  - Warehousing and Distribution
  - Road trains
  - Packaging
  - Intermodal

- Urban

Today vs. Tomorrow - The logistic hub
Class 8 GHG Reduction Potential - A Prospective Scenario
Via Vehicle Efficiency Gains and VMT Reductions

Includes VMT Reductions by hauling more freight per truck and use of intermodal

Excludes low carbon fuel savings

65% Ton-MPG improvement yields 40% fuel savings:
Gal/ton-mi or L/ton-km
Health and Social Benefits of Reducing GHG from Freight

• GHG Reduction- one piece of reducing climate change impact
  – Significant impact requires global action
• Reduced use of petroleum for transportation
  – A finite resource even as extraction techniques improve availability
• Reduced NOx and PM
• Lower freight transport cost (if aligned with commercial feasibility)
• Reduced urban congestion
Economic Growth Potential

• Traditionally freight growth is proportional to economic activity
  – Will shift to service and software economy reduce the linkage?
  – Impact of online purchasing and delivery?
  – Impact of additive manufacturing

• Efficient movement of goods is a key component of economic competitiveness
  – Facilitates growth potential
  – But only if economically efficient
BARRIERS TO IMPLEMENTATION
Barriers & Opportunities for Road Freight Efficiency

- Highly complex and expensive technologies must be supported by long-term, predictable ROI and/or forced by regulation.
  - If forced, expect slow acceptance by fleets
- Regulation is complex with significant potential unintended consequences.
  - Design for regulation rather than actual application
- Trailer economics do not easily support efficiency improvements
  - 3-4 trailers per tractor drives up cost vs fuel savings
  - Difficult to manage proper trailer match to tractors
  - Very long trailer life – slow turnover
  - Trailer ownership split between shippers and carriers
- Shipper’s area of influence
  - Manufacturing and distribution systems are based on low cost freight transportation. (Just-in-Time)
  - Packaging impact on freight density and volume
  - Warehousing and distribution patterns
  - Additive manufacturing impacts? – Moving raw material rather than finished products
- Infrastructure
  - Highway infrastructure and Intelligent Systems require government focus
  - Truck stops (Availability and Electrification)
  - Congestion mitigation
  - Intermodal facilities
- Lack of Long-Term Vision limits ability to plan and invest
  - Fuel prices? Alternative fuels?
  - Infrastructure?
  - Technology support
  - Urban freight delivery planning
Some Existing Regulations Hinder Efficiency

- Trailer rear marker light position (at top of trailer) reduces boat tail efficiency
- Inspection requirements limit skirt effectiveness on tractor and trailer
- Mirror requirements do not allow for substitution with cameras
- NOx control impact on engine efficiency and potential for even lower NOx in USA (& Canada?)
- Size and weight limits (Canada well ahead of USA)
- Platooning allowance (permitting close coupled platooning)
- Autonomous operation liability and permitting
- Axle load balance requirements limit 6x2 application
- US Heavy-Duty GHG regulation does not consider unique Canadian operations (climate, payloads, road speeds).
  - See comments from Canadian Trucking Alliance
Conclusions

• Significant potential improvements are possible but market is complex with multiple players requiring coordinated approach.
• Engine and vehicle technologies are already quite advanced, but many available efficiency features are only slowly gaining acceptance (especially for trailers)
  – There are no feasible technology options with huge benefits as for cars
  – Economic barriers (efficiency feature cost vs. fuel cost)
  – Regulatory barriers (length, weight, safety)
  – Infrastructure barriers (alternative fuels, congestion, truck stops, IT, docks, terminals, etc.)
• Efficiency needs to be measured in terms of moving freight, not moving trucks.
• Need for a comprehensive freight policy
  – Fuel supply/cost, fuel & vehicle taxes, fuel alternatives, infrastructure, intermodal, metropolitan freight delivery, size/weight consistency, speed, safety, data collection and analysis
• Freight growth will continue to outpace efficiency improvements without clear policy direction and coordination between vehicle manufacturers, carriers, fuel suppliers, shippers, and policy makers.
ADDITIONAL SLIDES
Best BSFC low speed marine diesel
* 13 g/hp-hr NOx  * Unlimited cooling capacity  *2 stroke
* 95 RPM  * Full Load  * Unlimited space and weight

Waste Heat Recover - max electrical output 12% of engine
* Uses exhaust turbine (diverts 10% of exhaust to power turbine) and rankine cycle from exhaust heat

Consent Decree 6 g/hp-hr NOx

2014 RMC Cycle GHG target = 475
2017 RMC Cycle GHG target = 460

Diesel 51% T.E.
Waste Heat Electrical adds 6%
57% total Thermal Eff
Engine Efficiency vs. Compression Ratio

Cost and complexity increase disproportionately as we approach theoretical efficiency limits.
PEM or SOFC Fuel Cell?

PEM is 50-60% EFFICIENT

- 45% of fuel energy must be extracted by coolant at temperatures around 70-80°C.
- For heavy-duty, this would mean a massive cooling system with negative aerodynamic consequences.
- With H2 from fossil sources GHG outcome is significantly worse than diesel hybrid.

Does it make sense to synthesize H2 from renewable electricity sources?

- Some analyses indicate only 22% of electrical energy makes it to the wheels.

On-board H2 storage is not capable of long-haul range requirements.

Typical mobile SOFC has only 30-35% electrical efficiency, but potential of 50-55% plus waste heat secondary cycle

- Long warm-up time
- Could be a possible option, but a long way from feasible.
- Still requires energy dense on-board fuel.
Heavy Duty BEV Potential

- BEV is feasible in non-weight sensitive urban delivery and utility applications
  - Cost and recharging remain barriers but improving
  - Relatively low potential for GHG reduction because fuel use is low
  - Urban NOx reduction potential
- BEV for regional or long haul is not feasible
  - Weight and size of battery pack
    - Won’t fit on tractors
    - Too much reduction in freight capacity
  - Very High cost
  - Charging time and infrastructure
  - Do not envision adequate progress in battery technology to change feasibility assessment.
One possible Full Electric Option...

- A **Plug In** vehicle able to charge from a “**Slide In**” track in the road
- Can **REALISTICLY** reduce the Energy Use by 50 % (Long haul) up to 75 % (Cars)
- Almost eliminates the use of fossil fuel
- Does not require any Rocket Science and can have realistic safety
- But requires development of safe and reliable method to electrify major roadways.
GHG Impact of NG as Motor Fuel

• Well-to-Tank CO₂ per Ca. LCFS
  – Domestic CNG 72% of diesel
  – Domestic LNG 76-88% of diesel

• Tank-to-Wheels (engine efficiency impact) at Tailpipe (including CO₂ % CH₄)
  – 115 -180% of diesel - stoichiometric NG
    • Heavily dependent on duty cycle
  – 105-130% of diesel – lean burn
  – 102-110% of diesel - lean burn (Direct Inject.)

• Methane emissions from LNG tank venting may become significant in older (less-used) vehicles.

• Net Result – GHG Emissions
  – Stoichiometric CNG: 83 -130% of diesel
  – Lean Burn CNG or LNG: 76 -114% of diesel
  – Lean Burn LNG DI: 78 -97% of diesel
  – Plus emissions from tank venting with LNG

Approximate GHG Relative to Diesel
Natural Gas Conclusions

• Fuel cost differential needed to drive the commercial market.
• Immediate potential GHG benefit of approximately 15% possible in some applications
• Barriers and needed actions
  – Must control fugitive methane emissions in production, distribution, operations, and maintenance
  – Need improved aerodynamic design to package CNG Tanks
  – Need to evaluate and improve engine technologies
  – Fuel distribution infrastructure is inadequate for longer hauls
  – Should consider alternate pathways to use NG like DME
• Other Impacts
  • Low cost NG may delay other alternatives
  • Venting of CH4 from older LNG vehicles may become a problem (LNG is “use it or lose it” and CH4 has 25-80 times GWP of CO2)
DME Should be Considered as a Fuel Alternative

- DME could play a strong role in the transition from petroleum based fuels and as a biofuel
  - Producible from a wide variety of fossil and bio based materials
    - Natural gas conversion to DME vs. flashing off at oil wells or from landfill gas
    - Highest biomass to fuel conversion efficiency
  - Relatively easy to store and transport (liquefies at low pressure & no venting)
  - High well-to-wheel efficiency
  - Clean (near zero soot) combustion
  - Excellent diesel cycle fuel
  - Non toxic and low GWP
  - Cost Effective
What Happened to Hybrid?

• North American Market for HD hybrid is essentially dead except for a small number of heavily subsidized buses.

• Why?
  – Optimum systems are application dependent, limiting volume opportunities
  – In use efficiency highly driver dependent & much lower than claims
  – Reliability, durability, downtime costs
  – Natural gas competition in urban applications
  – OBD certification requirements drive up cost and create liability concerns for non-integrated systems
  – Weight and space claims. Increased weight means less payload and more trips.
  – **Vehicle owners are finding the fuel savings are inadequate to cover initial and operating costs increases (maintenance, downtime, batteries, training)**

• Major suppliers dropped most hybrid offerings due to low sales and high cost

• Highest potential is in midrange size urban delivery vehicles and buses.
  – Urban drive cycles and less weight sensitive
2021 Timeframe Vehicle Efficiency Technologies

Tractor
- Engine Down speeding
- Engine down sizing (where applicable)
- Combustion improvements (cylinder pressure, chamber shape, fuel injection)
- Turbo efficiency/Turbo-compound Waste Heat Recovery
- Engine friction and fluid pumping
- 6 x 2 axle (low penetration)
- Liftable axle
- Improved tractor aero matched to aero trailer
- Improved tires
- Increased AMT penetration for tractors and vocational
- After treatment efficiency (may be used for NOx control)
- Low friction axle
- Predictive Cruise
- Smarter accessory management
- Better cab insulation
- Greater penetration of APUs (mainly battery electric)
- Tire pressure monitor

Trailer
- Improved Trailer skirts
- Improved Boat tail
- Gap reducer
- Low Crr Tires
- Weight

Barriers to Implementation
- State and provincial axle weight balance rules (6x2 issue)
- Wheel and brake inspection requirements (skirt optimization)
- Trailer rear light position requirements (boat tail optimization)
- Customer acceptance rate

Level of improvement potential is application specific.

Need to know baseline, duty cycles and assessment methods before evaluating outcomes.

Engine contribution should not be evaluated apart from vehicle load factors and driveline.

Combined efficiency potential improvements of about 14% for tractor-trailer and 4% for vocational vs. 2017.

From Volvo Truck Presentation to ARB Symposium 4/22/2015
Vehicle technology viability timeline - 2024

**Tractor**
- Improved predictive control, driver and vehicle management utilizing V2V and V2I
- Higher pressure efficient common rail?
- Variable valve actuation ??
- Increased cylinder pressure (~220-240 bar)
- Friction Reduction
- Improved accessories (alternator, air compressor, ...)
- Improvements to after-treatment low temp conversion efficiency and aging
- Alternative fuels penetration (NG, DME, ???)
- New cab - Tractor trailer aero integration
- Start/stop engine operation?
- Dual Clutch Transmission with further engine down-sizing
- Platooning?

**Trailer**
- Boat tail?
- Improved aerodynamics?

Combined efficiency potential improvements of about 20% for tractor-trailer and 7% for vocational vs. 2017.

Roadblocks to implementation
- Designing product for all customer applications
- Safety and inspection regulations
- Noise regulation
- Lower NOx demand
- EATS technical progression
- Vehicle impacts
- Manufacturability
- Cost of product
- Reliability of product
- Weight of product
- Payoff time of technology
- CERT cycles don’t match usage
- Aerodynamics / Vehicle efficiency improvements
Vehicle technology viability timeline

2025+ Highly Speculative

New Architecture; Highly Questionable Technology

Fuel economy change too difficult to forecast

- Waste Heat Recovery (high risk, low volume)
- Platooning
- Advanced combustion (PPC, HCCI, etc.)
- Alternative fueling (non-diesel, low carbon)
- No EGR
- New architectures (non 4-stroke diesel)
- Heavy electrification (PHEV with electrified major roads)
- Non-conventional hybrid (air, flywheel fluid)
- Longer/Heavier combinations
- Autonomous vehicles
- Electrified urban delivery

Roadblocks to implementation

- Infrastructure changes
- Weight/length regulations
- Regulation for platooning allowance
- Autonomous liability and regulations
- High speed combustion control
- High risk of failure
- New Emission legislations
- EATS technical progression
- Vehicle impacts – major redesign
- Manufacturability – huge investments
- Cost of product
- Reliability of product
- Weight of product
- Payoff time of technology
- Aerodynamics / Vehicle efficiency improvements (cooling)
V2V & V2I Enables Other Efficiency Features

• Platooning
• Green Light Optimization Speed Advisory (+ Green Wave for commercial vehicle)
• ecoDriving based on real-time traffic data
• Cooperative Active Cruise Control – based on interaction with other vehicles and infrastructure
• Road work site management (safe and increased throughput)
• Find available parking
• Passing assistance by real-time video information