US Heavy Duty Vehicle Fleets
Technologies for Reducing CO$_2$
An Industry Perspective

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VOLVO POWERTRAIN CORPORATION
Volvo Organisation

Business Areas
- Mack Trucks
- Renault Trucks
- Volvo Trucks
- BA Asia Incl. Nissan Diesel
- Buses
- Construction Equipment
- Volvo Penta
- Volvo Aero
- Financial Services

Business Units
- Volvo 3P
- Volvo Powertrain
- Volvo Parts
- Volvo Logistics
- Volvo Information Technology & Others

Over 225,000 diesel engines in 2006
World’s largest in 9-18 L size
Total U.S. Surface Transportation Diesel + Gasoline Fuel Use: 11.7 MBPD (Million Barrels Per Day)

Trucking Role in US Economy

• More than 80% of all communities in the United States are supplied exclusively by trucks

• Trucks hauled 10.7 billion tons of freight in 2005
  – 69% of all freight carried in the U.S. in terms of weight.
  – Virtually every item a person comes in contact with traveled on a truck at some point.

• Typical domestically-manufactured product moves by truck an average of six times before reaching its end customer

• Average imported product moves four times by truck once reaching a domestic port.

• Trucking represents roughly 5% of the U.S. gross domestic product

• The industry generated $625 billion in revenue during 2005, equivalent to 84% of all freight transportation revenues for all modes (truck, air, water, rail and pipeline)
Heavy Duty CO₂ Reduction

- Two fundamental strategies
  - Fuel Efficiency
  - Alternative (low carbon) fuels

- No feasible technology for Electric Vehicle due to high power consumption (inadequate battery capacity)
Drivers for FE and Alternative Fuels

- Pending oil shortage
- Rapid oil price increases
- CO$_2$ impact – Global Warming
  - Less fossil fuel burned = Less CO$_2$
- Key competitive feature
Fuel economy has always been a critical factor in diesel engine and truck marketing!

US ‘07 EMISSIONS TECHNOLOGY

- Primary selection criteria
  - Meet emissions limits
  - Reliability is most important for customers
  - Lowest operating cost
    - **Fuel economy**, maintenance, etc.
  - Durability
  - Performance

Note: fuel economy is a key criterion.
Truck Fuel Cost is a Big Factor

Fuel may now surpass driver as biggest single long haul operating cost!

- Cars: $30,000 Vehicle
- Class 8 Trucks: $100,000 Vehicle Cost
- 800,000 Miles @ $3/ Gal
Heavy Duty Vehicle Fuel Efficiency is a Complex Issue

Many types of vehicles with different functions

How to Define & Measure Efficiency?
MPG is not an appropriate efficiency measure

- .5 Tons 96 cu-ft 22 MPG
- 30 Tons 4000 cu-ft 6.5 MPG
- 80 Tons 11000 cu-ft 3.5 MPG

All numbers are approximate.
Freight movement energy efficiency is heavily influenced by congestion and vehicle size regulations.
Fuel Consumption Drivers

Engine

Daily Customer variables

- Drive line friction
- Air resistance
- Auxiliaries
- Rolling resistance
- Idle time
- Driving habits
- Speed
- GCW
- Road type
- Weather
- Others

Trailer aerodynamic features, tires, and gap have big impact
Key Factors in HD Truck Efficiency

Powertrain

Engine
- Combustion/fuel injection
- Peak cylinder pressure
- Turbocharging
  - Increased Efficiency
  - Increased pressure ratio
- Friction and parasitic
- Exhaust aftertreatment
- Turbo compound
  - Mechanical
  - Electric
- Waste heat recovery

Drivetrain
- Transmission
  - Automated manual
  - CVT
  - Powershift
- Hybrid
  - Electric
    - Parallel
    - series
  - Hydraulic

Continuously improving
New opportunity for optimization
Coming Soon?
Key Factors in HD Truck Efficiency

Vehicle

**Tractor**
- Aerodynamics
  - Frontal area
  - Side skirts
  - Roof fairings
  - Mirrors
  - Air blowing
- Rolling Resistance
  - Super single tires
  - Proper inflation
- Reduced Mass

**Trailers**
- Rolling resistance
  - Super Single tires
  - Rolling resistance
- Aerodynamics
  - Side skirts
  - Boat tail
- Weight

**Integration**
- Matching Powertrain to intended load/speed
- Trailer gap
- Accessories
  - Air compressor
  - Air conditioning
  - Cooling system
  - Power steering
- Idle management
  - APU
  - Truck stop electrification
- Energy storage systems

Generally Deployed

Increasingly Deployed
Key Factors in HD Truck Efficiency

Regulation and Public policy
- Road Speed limiting
- Weight limits
- Trailer combinations
- Length limits
- Driver Hours of Service
- Congestion mitigation
- Incentives (hybrid)

Logistics
- Load management/backloads
- Route Optimization
  - Congestion Avoidance
  - Distance Minimization
- Vehicle management
  - Road speed limiting
  - Driver management
    - Smart gearing
    - Acceleration control
    - Idle management
  - Cruise management via GPS
    (anticipating grade and speed limit changes)

State-to-state inconsistency is a major barrier to efficient freight movement.

Significant gains have been realized in logistics. Still room for improvement.
Where are we?

- 1950?
- 1980
- 2007

Big change in tractors.
Trailer changes??
- Used as rolling warehouse
- Three trailers per tractor
- Often owned by shipper
- Least cost is main consideration
Most Long Haul Tractors are Incorporating Aero Features
Still Some Retain Traditional Look
US NOx Reduction Impact on FE

Relative Engine Efficiency

15-20%

Unlimited NOx Potential

Actual with NOx Reduction


NOx Level

11 0

Electronic Variable Timing

Consent Decree

EGR, VGT

HEGR, DPF

NOx EATS .2 gr/hp-hr

Advances in injection, PCP, turbocharging, friction, etc.

Volvo Powertrain
Vehicle Electrification/Hybrid

Hybrid for Stop/Go Duty Cycle:
- Improved Fuel Economy (up to 50%)
- Improved Performance
  - Launch assist
- Reduced Emissions (per Ton-mile)
- Reduced transients and Idle operations
- Recovery/recycling of braking energy
- Quieter Operation
- Eliminates need for APU (uses battery power)

Electric Auxiliaries for Long Haul
- Modulate pumping, fans, air compressor, air conditioning, power steering
- Improved fuel economy
- Improved cooling
- Facilitate reduced idling
- 3-5% Fuel Economy improvement potential

Long Haul Hybrid with Electric Auxiliaries
- Hybrid electrical generator for quick charging of batteries
- Electric turbo-compound with power to auxiliaries and electric motor
- Hybrid battery system to eliminate idle
- 10-15% FE improvement potential (including idle elimination)

Incentives are needed to promote technology introduction until volume is sufficient to lower costs
Fuels for the future

How do we evaluate the alternatives?

- Sustainable resource availability
- Well-to-wheel energy efficiency and CO2 emissions
- Well-to-wheel regulated and unregulated emissions
- Economy & infrastructure
- Other considerations
  - energy density
  - safety and health (fuel handling)
  - specific issues/concerns related to the different driveline applications (trucks, buses, marine, stationary)
  - political environment
  - customer perceptions
"Well-to-wheel" analysis (Volvo study)

Energy efficiency and Greenhouse gases

- Fossil
- Renewables

Bar chart showing energy efficiency and GHG emissions for various energy sources:

- Diesel (crude oil)
- DME (natural gas)
- MeOH (natural gas)
- CNG (natural gas)
- Synthetic diesel (natural gas)
- DME (wood, black liquor)
- MeOH (wood, black liquor)
- Biogas (sewage)
- DME (wood)
- MeOH (wood)
- Synthetic diesel (cellulose)
- FAME (soy, rape)
- Ethanol (cellulose)
- Ethanol (grain)

- Best energy efficiency
- Least Infrastructure Impact
Heavy Truck Improvements

• Aerodynamics (largely available)
• Reduced trailer gap (largely applied)
• Tires - low resistance, super singles (available with increasing use)
• Transmission technologies – forcing use of top gear, managing poor driver habits (Automated Manual Transmissions use is increasing rapidly)
• Idling Reduction
  ➢ APU
  ➢ Truck stop electrification/climate systems
  ➢ Battery powered systems
  ➢ Cold storage systems (for air conditioning)
• Trailer Improvements
  ➢ Aerodynamics (skirts and boat tail)
  ➢ Tires- low rolling resistance
Potential Government Activity

- **Higher loads**
  - Trailer size (capacity and allow for boat tail)
  - Multiple trailers
  - Load limits (GCW)

- **Reduce traffic congestion**

- **Road Speeds**

- **Mandatory vehicle road speed limits**

- **Extend and increase incentives to promote new technologies**
  - Hybrid
  - Other Fuel Economy measures
## Biggest Opportunities for Long Haul Trucks

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Est. FE Gain</th>
<th>Technology Readiness</th>
<th>Issues/Obstacles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low rolling resistance tires (super singles) on tractors and trailers</td>
<td>3%</td>
<td>Available for high volume use. Increasingly deployed.</td>
<td>Cost &amp; life factors. Skepticism by operators. Trailer ownership split</td>
</tr>
<tr>
<td>Turbo Compound</td>
<td>3-5%</td>
<td>Concept proven with some production, but outside USA.</td>
<td>Cost and reliability Package space</td>
</tr>
<tr>
<td>Trailer side skirts</td>
<td>4%</td>
<td>Commercially available</td>
<td>Trailer/truck ratio &gt;3 Trailer ownership split Skirt damage Knowledge/incentives</td>
</tr>
<tr>
<td>Mandatory Road Speed limit to 65 MPH (controlled via truck software)</td>
<td>5% average</td>
<td>Available in all class 8 trucks since mid 90’s</td>
<td>Drivers paid by mile Car traffic meshing/safety Congressional Action</td>
</tr>
<tr>
<td>Eliminate Idling in sleeper mode</td>
<td>5-7%</td>
<td>Available: APU, battery, storage systems, shore power in some stops, engine stop-start systems, IdleAire system</td>
<td>Storage system performance Shore power availability IdleAire system availability &amp; cost Cost &amp; weight for on board systems California APU DPF requirement Stop/start cycle disturbs sleep</td>
</tr>
<tr>
<td>Increase weight, length, and trailer combination limits</td>
<td>Fewer trucks needed on road</td>
<td>None required</td>
<td>Safety concerns Road damage concerns State variations</td>
</tr>
<tr>
<td>Optimization of powertrain and engine to duty cycle</td>
<td>2-5%</td>
<td>Available</td>
<td>Customer awareness Adequate sales engineering support Variation in duty cycle</td>
</tr>
<tr>
<td>Trailer gap reduction</td>
<td>3%</td>
<td>Commercially Available. Deployed in some fleets.</td>
<td>Mix of trailers hauled. Turning radius reduction DPF size</td>
</tr>
</tbody>
</table>
Conclusions

• Customer focus on fuel economy is extremely high, forcing FE as key competitive feature.
• Improvements are possible by better application of existing technologies.
• Steady improvement in engines has been largely offset by NOx emissions requirements.
• Big gains possible by use of hybrid technology on urban vehicles (highly cyclical duty cycle).
• Integration of engine, transmission, driveline, and hybrid features offers future potential.
• Government policy on road speed and vehicle size/weight limits has significant potential.
• Higher fuel costs increase new technology cost effectiveness.
Appendix – not for verbal presentation
Engine NOx Aftertreatment

- Improvements in catalytic NOx conversion can free up diesel engineers to improve fuel efficiency
- Urea SCR (Selective Catalytic Reduction)
  - Effectiveness of over 90% NOx reduction possible within key operating zones
  - Allows engine to run at higher cycle efficiency with higher NOx, which is reduced via ammonia (from urea) in the catalyst.
  - Improve fuel efficiency for 2010, even after accounting for urea.
  - Reduced heat rejection due to lower EGR rate.
  - Requires injection of urea into exhaust catalyst (urea tank, urea injection system, controls, catalyst, etc.)
Cooled EGR Impact on FE

Requires higher pressure in exhaust system than intake to drive exhaust gas. (Gas pumping losses)

Pumping loss incurred due to EGR flow requirement.

Peak cylinder pressure increases due to EGR.

More work required in turbo-machinery (higher boost).

Higher heat rejection means bigger fans with more on time and drives more truck frontal area (negative aerodynamics effect).

EGR routed from Exhaust Manifold to intake manifold.
Engine Design Improvements

• Turbo-compounding
  – Use secondary power turbine in exhaust to extract energy and feed back power
    • Mechanical, electrical, hydraulic all have potential
  – Could also generate electricity using power turbine
  – Can allow lower speed engine operation (low speed torque)
  – Hardware cost, reliability, and control complexity are key concerns
  – Payback improves as fuel costs increase.
  – Some systems already in production
Engine Design Improvements

- Diesel cycle efficiency can be improved with high compression ratio and higher cylinder pressure.
  - Requires stronger major components to survive higher loads
  - Internal temperatures also increase
  - Very high boost pressure requires complex and expensive turbos
  - Needed improvements in turbo efficiency are beyond current manufacturing capability.

- Variable Valve Actuation
  - Emissions control
  - Cylinder cut-out for light load

- Continued improvement in fuel injection in both unit and common rail systems

Recent improvement in these areas have been used to improve emissions and offset related efficiency losses.
Engine Design Improvements

• Further reduction in parasitic losses can yield 2-3%.
  – Electronic thermostat (coolant and oil)
  – Modulating coolant pump
  – Modulating oil pump
  – Better fan control
  – Air compressor (electric or clutch)
  – Electric Fuel Pump