

Heavy Duty Diesel Engine and Powertrains for 2010 and Beyond

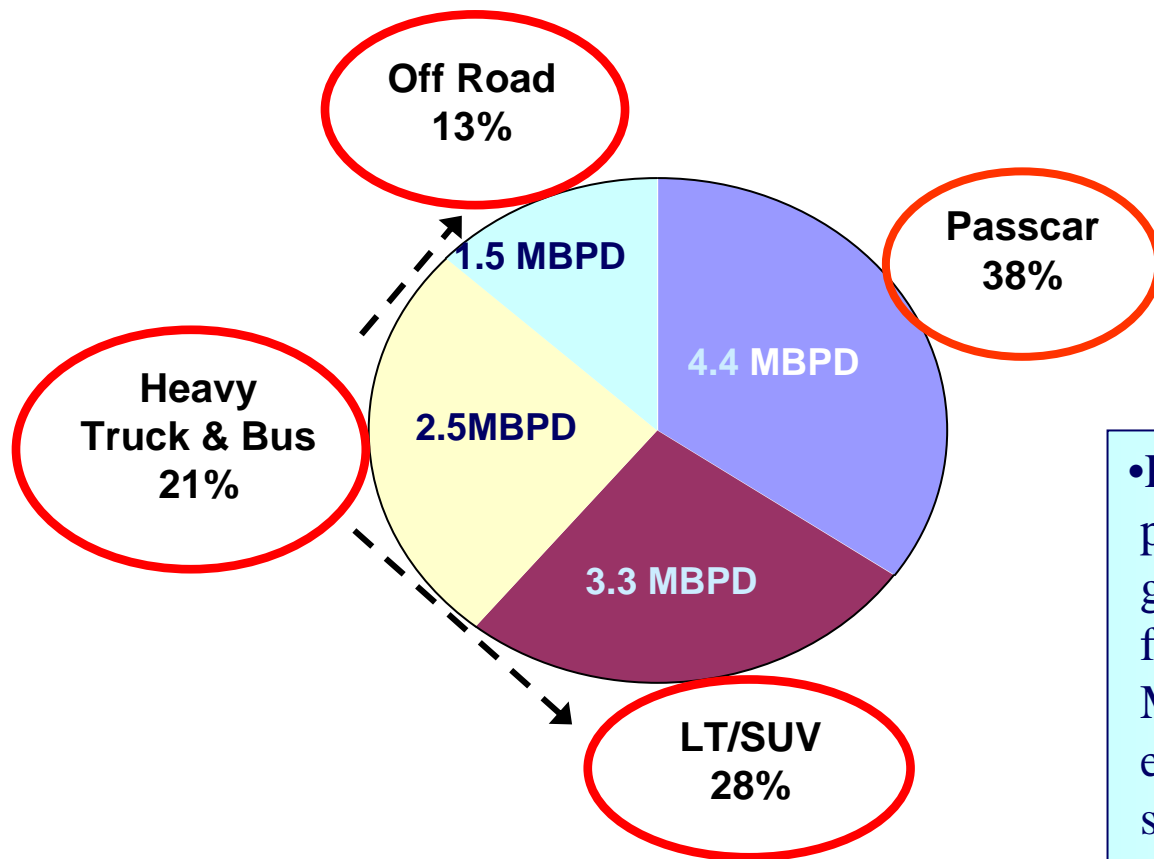
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Volvo Powertrain



VOLVO

Powertrain

US Surface Transport Fuel Usage



• Heavy duty fuel use is projected to grow with freight growth while light duty is falling due to improved LD MPG and conversion to electric systems. HD could surpass LD by 2040 or sooner.

**Total U.S. Surface Transportation
Diesel + Gasoline Fuel Use: 11.7 MBPD
(Million Barrels Per Day)**

Trans. Energy Data Book, Edition 25, 2006

2010 Technology

- **Primary impact of EPA 2010 regulation -NO_x Reduction to .2 gr/hp-hr**
- **UREA SCR is the only technology offered that will meet NO_x requirement without use of credits.**
- **Efficient NO_x aftertreatment allows higher in cylinder NO_x generation and facilitates combustion efficiency.**
- **Other Benefits**
 - **Lower heat rejection to coolant**
 - **Higher power density *500 HP/ 1750 ft-lbs for Volvo D13 (12.8 Liter)**
 - **No change to base engine required**
 - **Simplifies turbochargers and cooling system**
 - **Facilitates passive regeneration of DPF (less fuel needed in most applications)**

[SCR System](#)

2010 Technology

- **SCR Efficiency gains proven and demonstrated:**
 - **4% reduction in diesel fuel (compared to EPA 2007) with 2.5% Diesel Exhaust Fluid**
 - **Estimated 6-7% SCR Fuel Economy improvement vs. EPA 2010 with EGR only at .5 gr./hp-hr NO_x**
 - **2% base engine efficiency loss for US10 massive EGR vs. US07**
 - **1% loss for frequent active DPF regeneration**
 - **2% net cost savings in operation (compared to US 2007)**
 - **5% net savings in operation (compared to massive EGR US10)**
 - **Still working on optimization (i.e. more to come)**

SCR System

SCR Impact on Petroleum and CO₂

- **DEF (Urea) is made from natural gas**
 - **Equivalent to alternate fuel – natural gas displacing 4% petroleum use compared to EPA 2007 engine.**
- **SCR results in significant reduction of petroleum use and in green house gas emissions while reducing operating cost.**
 - **Compared to EPA 2007:**
 - **Each gallon of DEF reduces diesel use by ~1.5 gallons**
 - **Each gallon of DEF eliminates ~15 KG CO₂ (equal to 1.3 gallons diesel)**
 - **Compared to Massive EGR for EPA 2010:**
 - **Each gallon of DEF reduces diesel use by ~3 gallons**
 - **Each gallon of DEF eliminates ~33 KG CO₂ (equal to 2.8 gallons diesel)**

2010 Hardware on Mack Test Truck



2010 Hardware – Volvo Truck



Beyond 2010

What comes next?

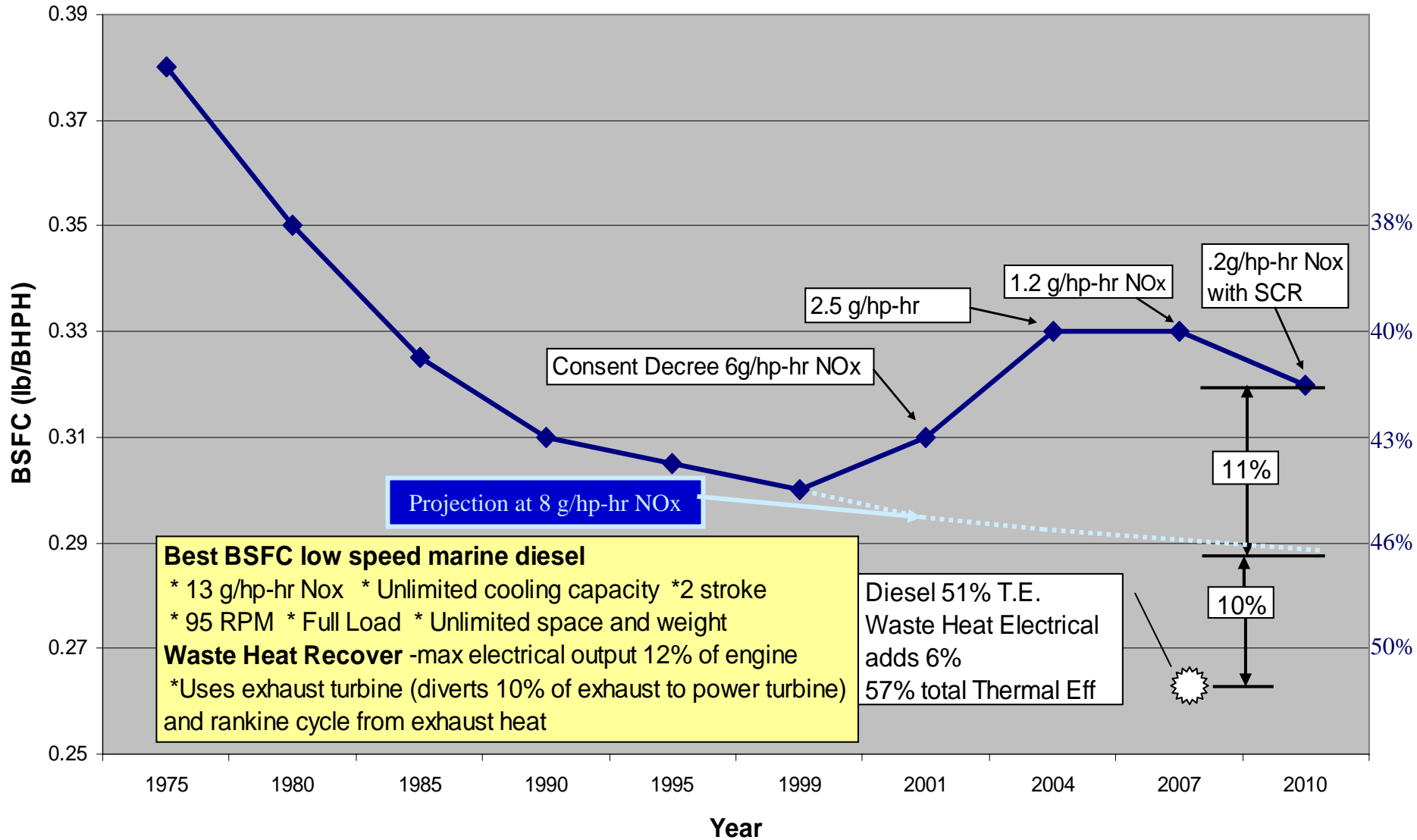
Fundamental Strategies for Engine and Powertrain Efficiency

- Combustion and Gas Management
 - In cylinder optimization
 - Fuel Injection rate, shape, frequency
 - Injection timing and strategy
 - Mixing
 - Minimizing heat transfer
 - Turbocharger Efficiency Optimization
 - Exhaust Gas Recirculation
 - Flow volume and loss minimization
 - Cooling optimization
 - Intake and Exhaust Loss Minimization
- Engine and Driveline Friction Reduction
- Waste Heat Recovery
 - Turbocompound
 - External Rankin or Brayton cycles
 - Thermo Electric or Thermo Acoustic Conversion
- Heavy Duty Hybridization
- NOx Aftertreatment Efficiency Gains
- Engine and Drivetrain System Integration
 - Optimize the engine operation over the duty cycle
 - Reduce driver influence on efficiency
 - Maximize availability of waste heat for energy recovery



Historical
Research
Effort
And
Technology
Maturity

Historical Look at Best Point BSFC HD On-Highway Diesels



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

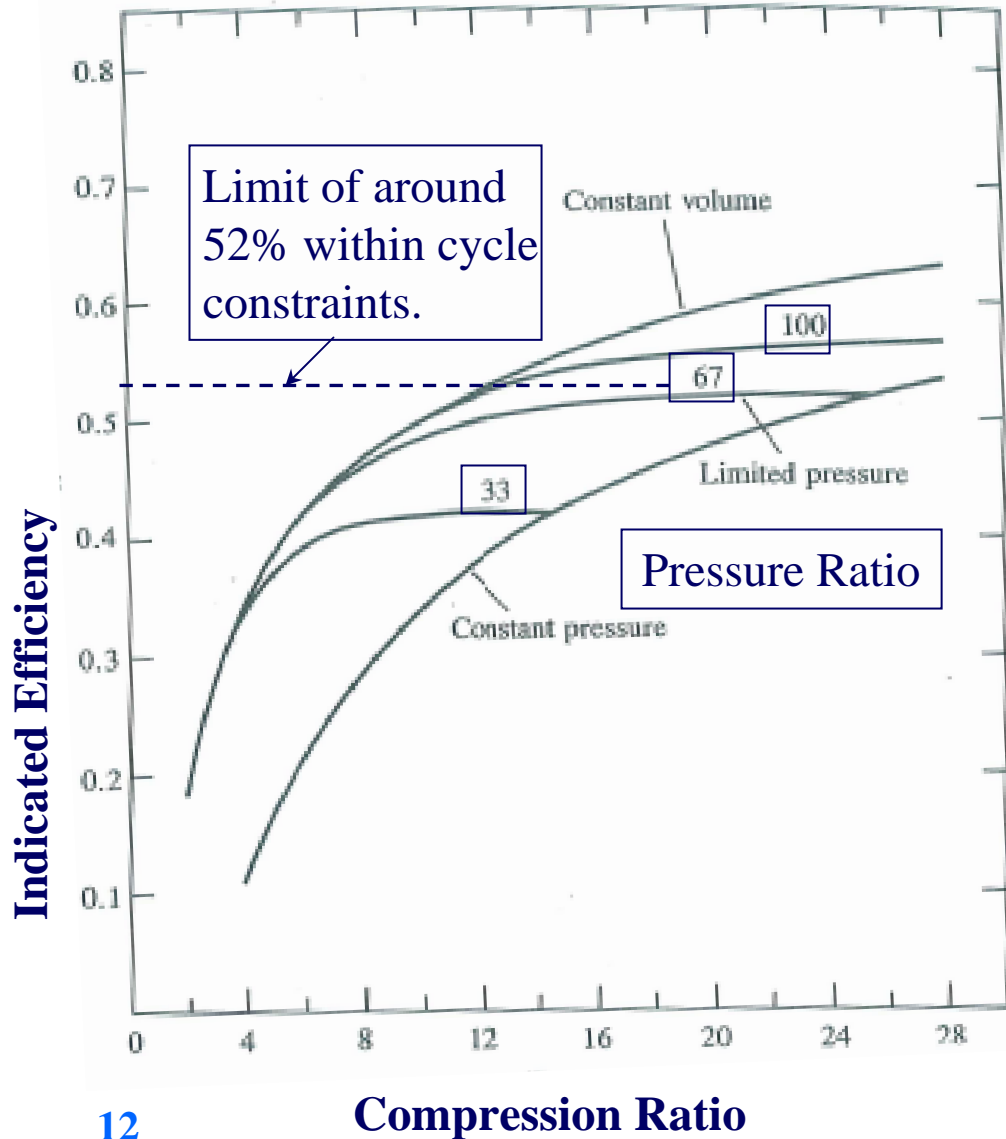
Diesel 51% T.E.
 Waste Heat Electrical adds 6%
 57% total Thermal Eff

Some Observations About Diesel Efficiency

- Historical gains for best point from 1980 to 1999 were about .5% per year.
- NOx reductions in the last decade have had a big negative impact on best point fuel efficiency.
 - EGR has shifted the gas pumping (via turbocharger) from positive to negative (pumping loss). Increased EGR rates drive higher losses.
 - Injection timing optimized for NOx reduction rather than efficiency

Diesel Cycle Efficiency Limitations

- Cycle is pressure limited at pressure ratio of about 70.
- In cylinder practical Indicated Efficiency limit of around 52%
- NOx control forces injection timing away from best point – 3% TE
- For Brake Efficiency Deduct:
 - Gas pumping losses due to EGR – 1% TE
 - Friction losses – 5 % TE
- With these losses engine TE is ~43%



Potential Improvements in Diesel Efficiency

- Improved NOx aftertreatment could offer potential to gain up to ~3% thermal efficiency.
 - Allows more optimum combustion
 - Reduces need for EGR and associated pumping losses
 - Need to take care of reductant impact on CO₂
- Friction reduction could yield 1-2%
- This would yield a base engine Thermal Efficiency of around 47%
- Waste heat recovery potential – 3-5% Thermal Efficiency possible
 - Use EGR and exhaust heat energy
 - Rankin cycle can significantly enhance total efficiency
 - Adds weight, volume and low temperature cooling to condense working fluid.
 - Much work is still needed to fit this in a truck and to enhance efficiency.
- All this could yield an engine system at 52% thermal efficiency (20% better than current)
- Powertrain integration offers potential to operate the engine closer to peak efficiency points.
 - Avoid idling and light load

An Integrated Powertrain for Fuel Efficiency

Electric Turbocompound with Electric Auxiliaries and Mild Hybrid for Long Haul

Advantages of Combined system

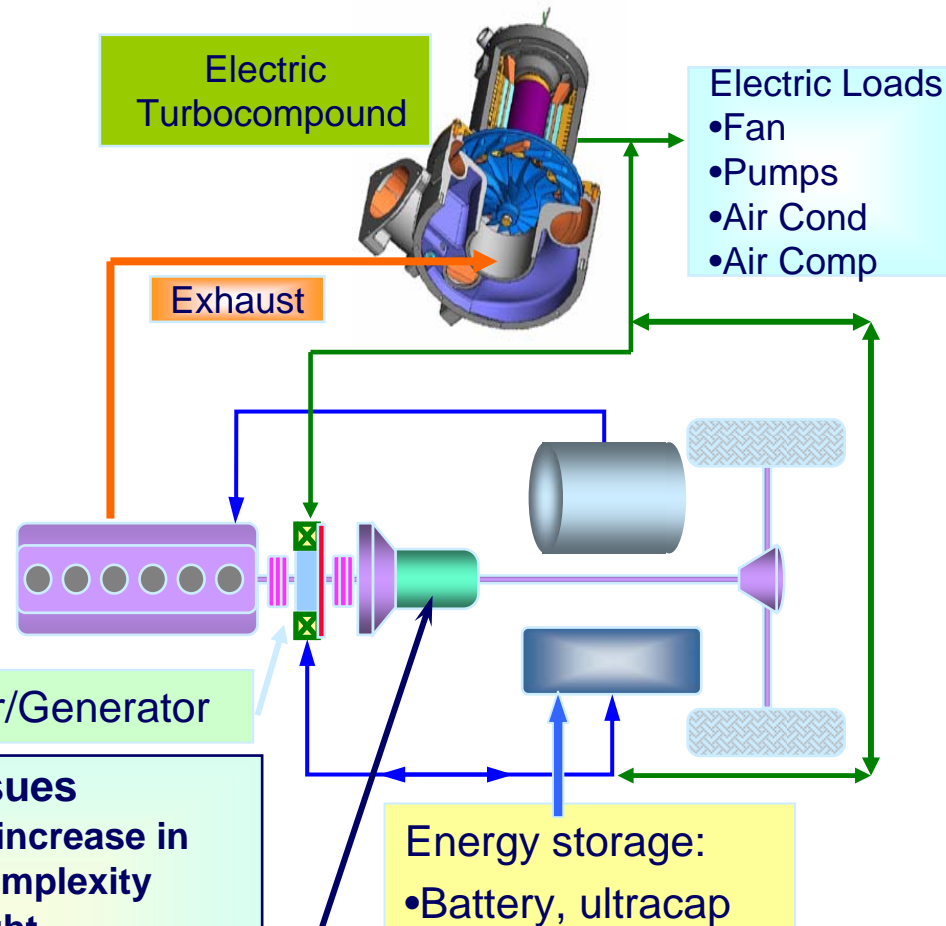
- Electric Auxiliaries can be modulated to meet system demand
- Mild hybrid motor takes electricity above auxiliary requirements
- Energy Storage can be used to run auxiliaries needed for hotel function to avoid idling for driver needs.
- Eliminate idling and light load diesel operation by using electric motor
- Optimize engine to run in new duty cycle
- Manage exhaust temperatures to optimize waste heat recovery and aftertreatment
- Fuel savings -10% or more depending on idling reduction savings

Issues

- Significant increase in cost and complexity
- Added weight
- Need better batteries
- Extensive development needed

Smart Transmission

- Senses load and grade
- Optimal shifting
- Minimize driver influence



Possible Class 8 Technology Scenario

- Look at each type of technology.
- What is the likely Fuel Efficiency Benefit from the technology including installation impacts?
- What percentage of the class 8 fleet can effectively deploy the technology?
- When did/will technology deployment begin and when will it be mature?
- Determine net impact on new truck fuel efficiency over time.

Major Contributors to Long Haul Truck Freight Efficiency

Engine Technology

- Diesel Combustion Efficiency
- Waste Heat Recovery
- Nox aftertreatment improvements
- Engine friction reduction
- Engine Auxiliaries (water/oil pump)
- Other New Technology Developments

Truck Technology

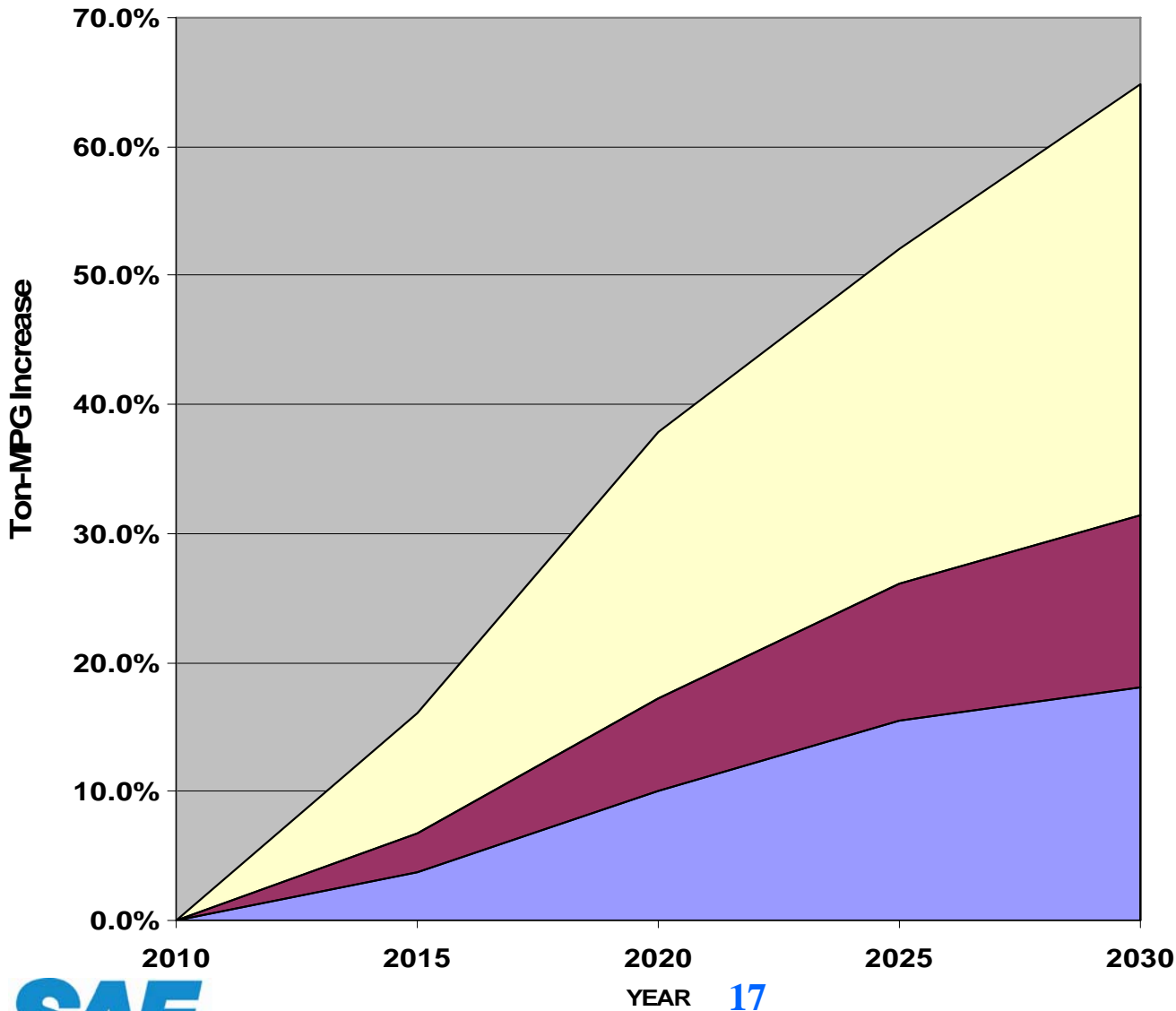
- Transmission & Driveline Efficiency
- Powertrain integration (includes engine)
- Cooling optimization
- Vehicle Auxiliaries (Air comp, PS pump, Air Cond, Fan, Alternator)
- Aerodynamics (tractor)
- Weight
- All Tractor Tires
- Trailer Gap or vortex stabilizer
- Smart Navigation
- Mild long-haul hybrid (add to no-idle)
- Full Hybrid

Fleet Operations

- Logistics
- Trailers -Tires, Aero, Weight
- Longer Combinations & increased weight (assuming consistent state regulations)
- Intermodal (rail)
- Driver Training
- Trailer gap control (add to truck design)
- Idle Elimination
- Road speed reduce 7 MPH

Class 8 Ton-MPG - A Prospective Scenario

Potential Efficiency Gains



- Trailers and Fleet Operations
- Truck Technologies
- Engine Technologies

65% Ton-MPG improvement yields 40% fuel savings.

Engine gains yield ~1%/year. Double the 1980 to 1999 average

Fuel Efficiency Return on Investment

- **Two major competitive features for trucks**
 - Fuel Efficiency
 - Purchase cost (big increases driven by recent emissions requirements)
- **Typically truck purchasers look at fuel efficiency as part of their operating cost.**
 - **Payback time expected – about two years**
 - Trade cycle for first owner usually ~ 4 years
 - Uncertain value of specific FE features to second owner – resale value?
 - Low confidence in achieving stated FE, especially if in small increments.
 - **Payback per year is proportional to fuel burned and cost of fuel in the operation.**
 - Longhaul operation at 150,000 miles/year and 6 MPG
 - 25,000 gallons per year; 50,000 gal/2years
 - 1% FE worth ~\$2000 @ \$4/gallon diesel
 - Short haul or vocational typically place lower value on FE
 - Often smaller fleets with less tracking of cost per truck
 - Fewer miles and less fuel burned per truck
 - Actual fuel savings heavily dependent on specific operation
- **Costs include not only engine technology, but installation impact on truck design.**
- **Trailer ROI reduced 3-6X: 3 or more trailers per tractor and often owned by shippers.**
- **The big question: What will diesel fuel cost in 5-12 years as new technologies unfold?**

Overall Conclusions

- There are no easy, big gains.
- Engine efficiencies can be improved, but incremental improvements become tougher with each step.
- Drivetrain integration with engine and vehicle become more critical with new smart transmissions, hybrid systems, aftertreatment, and waste heat recovery.
- In vehicle demonstration is critically needed to prove feasibility in real applications.
- Trailers and fleet operations technologies offer big opportunities.
- Ultimately, we need all this combined with low carbon fuels to meet sustainability and CO2 targets.
- Government and the heavy truck industry have a good track record working together, but much more focus and effort is needed and warranted by the growing demand for freight transport and resulting fuel usage.

Appendix : DEF & Diesel Lifecycle GHG

Life cycle CO2 for solid urea = 1.8 KG CO2/KG solid urea (pg 13 of attached file - using highest estimate)

At 32.5% urea aqueous urea (DEF) weighs 4.2 KG/gallon and emits 2.5 KG CO2/gallon

$$(4.2 \times .325 \times 1.8)$$

Life Cycle CO2 for diesel:

Crude production efficiency: 86% (i.e 86% of fuel energy goes into the tank)

Diesel emits 10.1 KG CO2/gallon at tail pipe

Life cycle emission = $10.1 / .86 = 11.7$ KG CO2/gallon

For US10 vs US07, we project 1.5 gallon diesel saving per gallon of DEF (we expect 2.5% DEF use and 4% diesel reduction)

This means 15 KG CO2 reduction per gallon of DEF

$$(1.5 \text{ gal} \times 11.7 \text{ KG/gal}) - (1 \text{ gal} \times 2.5 \text{ KG/gal}) = 15$$

$$(1.5 \text{ gallon Diesel savings}) - (1 \text{ gallon DEF GHG emissions})$$



GHG_Emission_Fertilizer%20Prod...

A Review of Greenhouse Gas Emission Factors for Fertiliser Production.

Sam Wood and Annette Cowie

Research and Development Division, State Forests of New South Wales.

Cooperative Research Centre for Greenhouse Accounting