US Heavy Duty Vehicle Fleets
Technologies for Reducing CO_2
An Industry Perspective

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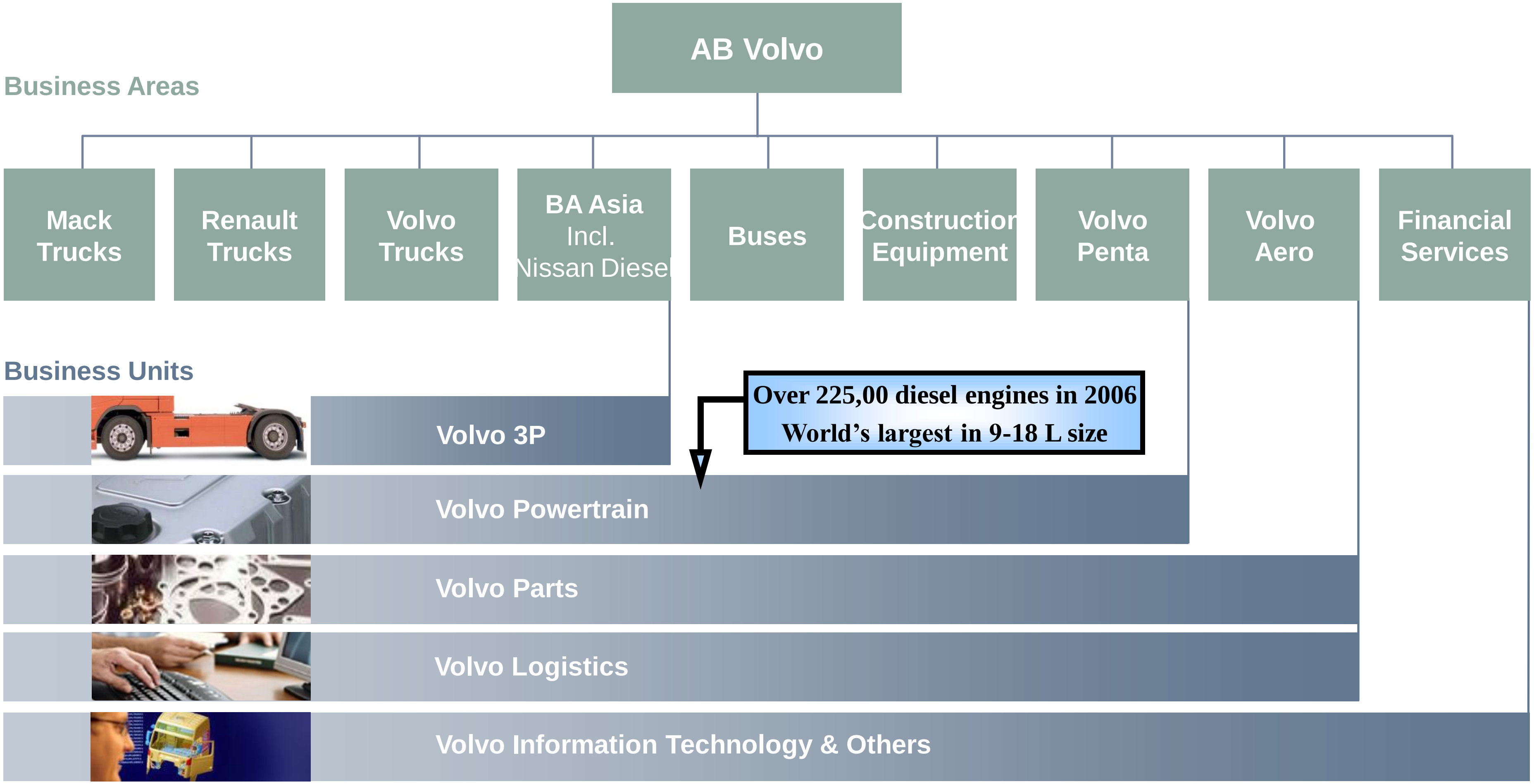
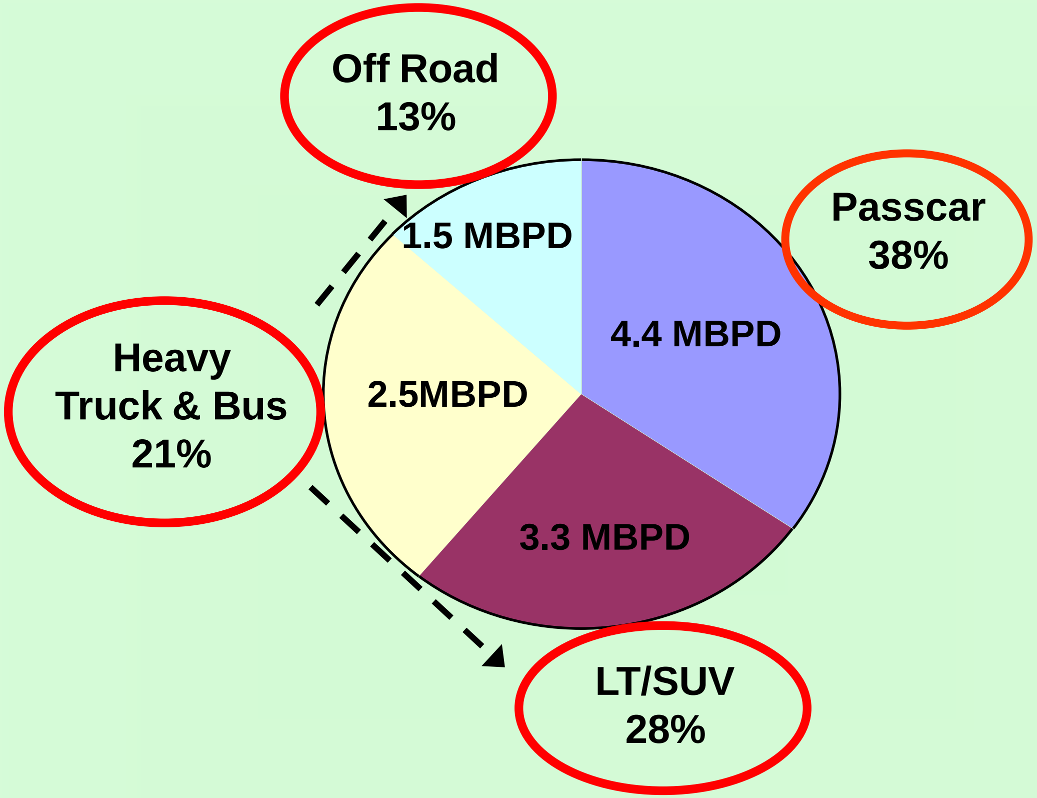


US Surface Transport Fuel Usage



Total U.S. Surface Transportation
Diesel + Gasoline Fuel Use: 11.7 MBPD
(Million Barrels Per Day)
Trans. Energy Data Book, Edition 25, 2006

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 CO_2 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

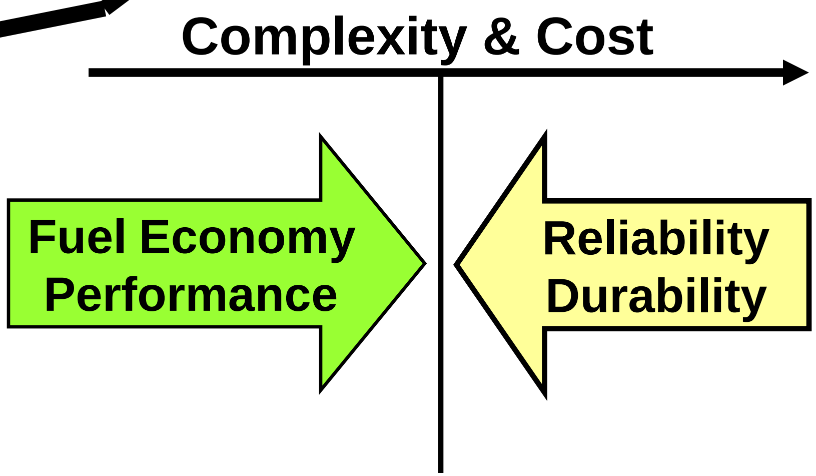
Fuel economy has always been a critical factor in diesel engine and truck marketing!

US '07 EMISSIONS TECHNOLOGY

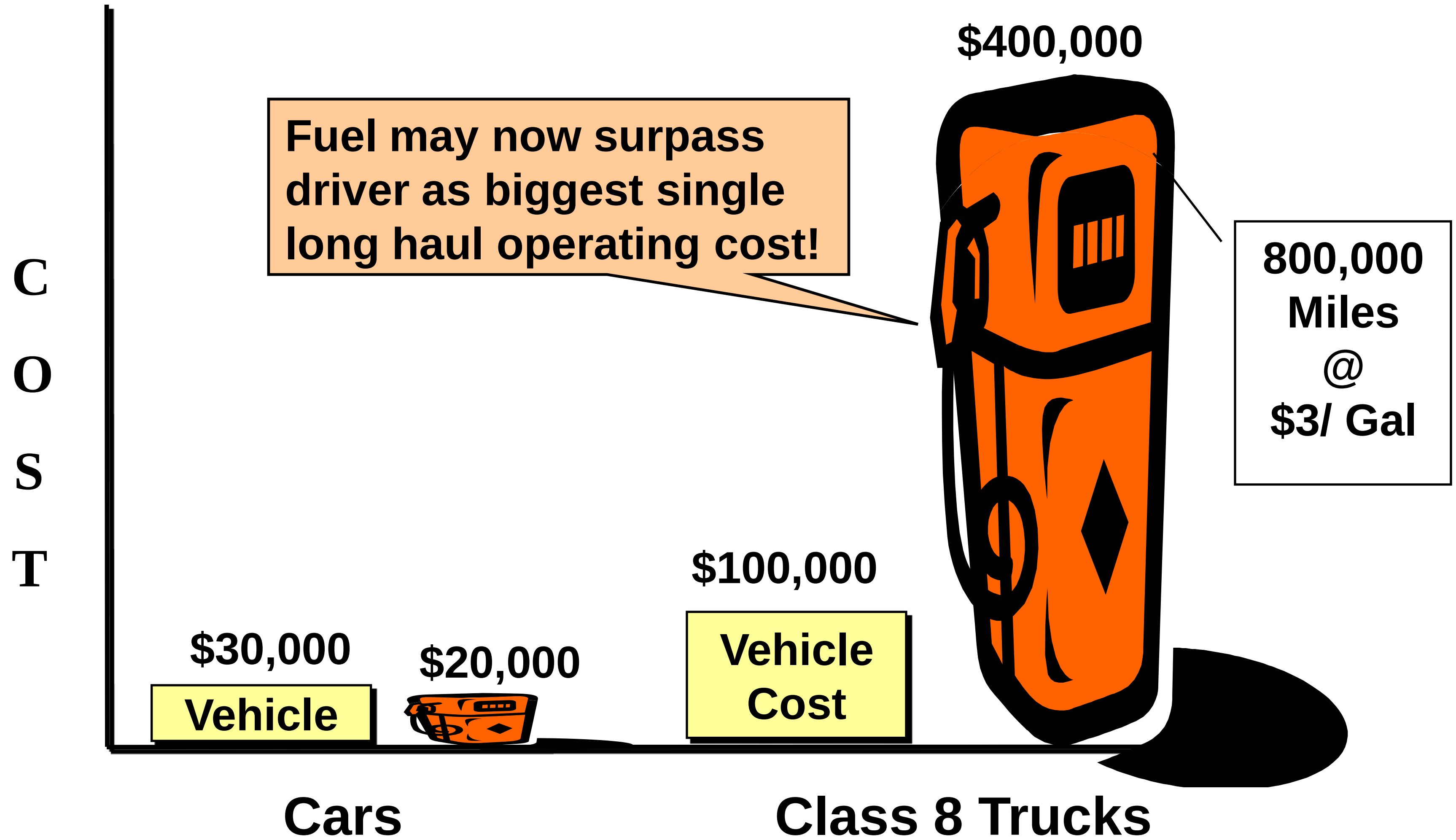
- Primary selection criteria
  - ✓ Meet emissions limits
  - ✓ Reliability is most important for customers
  - ✓ Lowest operating cost
    - ➢ **Fuel economy**, maintenance, etc.
  - ✓ Durability
  - ✓ Performance

Slide taken from presentation on US07 engine technology.

Note: fuel economy is a key criterion.



Truck Fuel Cost is a Big Factor

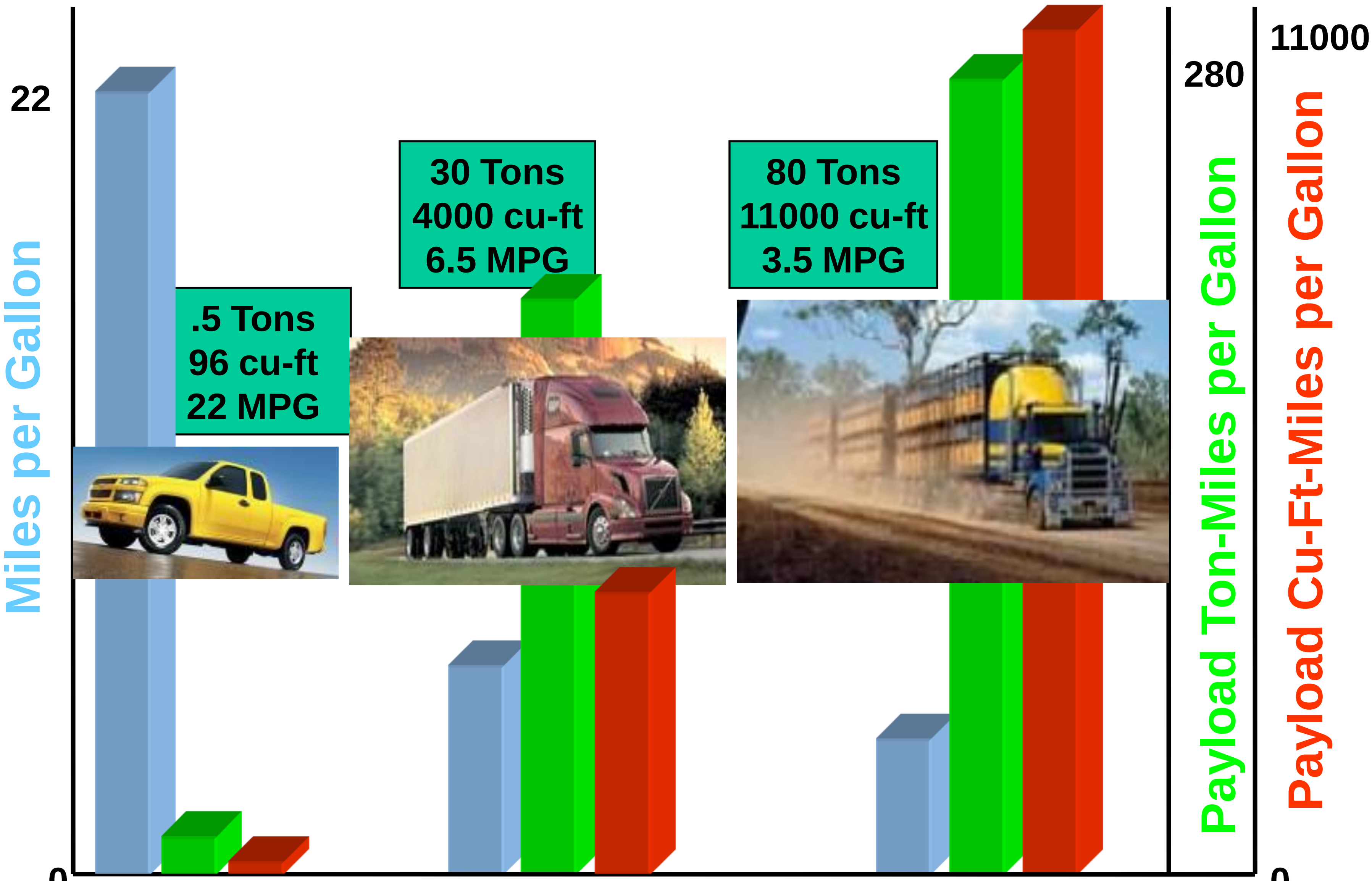


Heavy Duty Vehicle Fuel Efficiency is a Complex Issue

Many types of vehicles with different functions

How to Define & Measure Efficiency?

MPG is not an appropriate efficiency measure

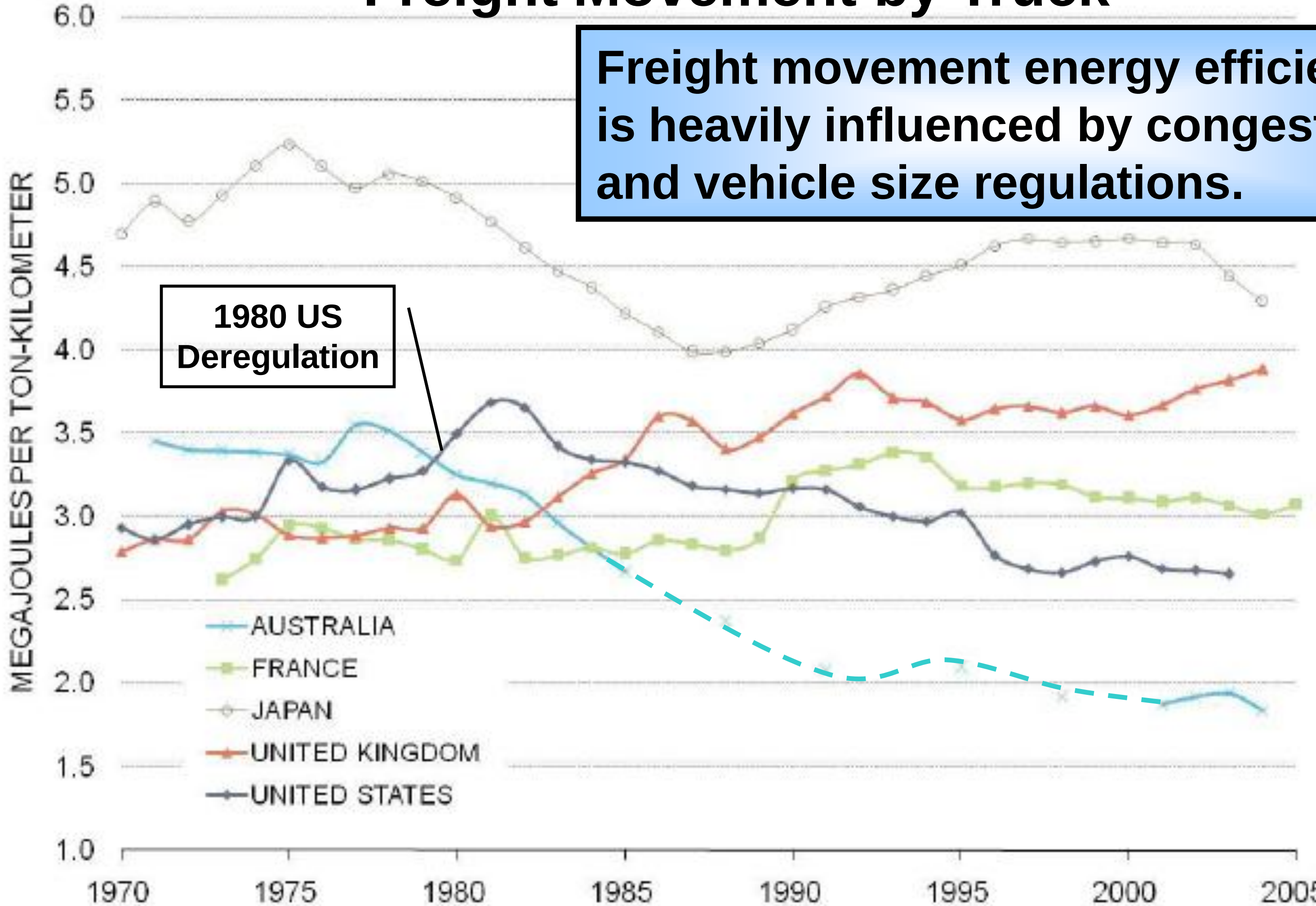


All numbers are approximate

Modal Energy Intensity

Freight Movement by Truck

Freight movement energy efficiency is heavily influenced by congestion and vehicle size regulations.



Taken from icct presentation to International Workshop on Fuel Efficient Policies – Paris, June 22, 2007

Fuel Consumption Drivers

Drive line friction

Air resistance

Auxiliaries

Rolling resistance

Engine

Daily Customer variables

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

Continuously improving

New opportunity for optimization

Coming Soon?

Drivetrain

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

Key Factors in HD Truck Efficiency
Vehicle

Generally Deployed

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

Increasingly Deployed

Key Factors in HD Truck Efficiency
Regulation and Logistic

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

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

Significant gains have been realized in logistics. Still room for improvement

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)

Where are we?

1950?

1980

2007

Big change in tractors.

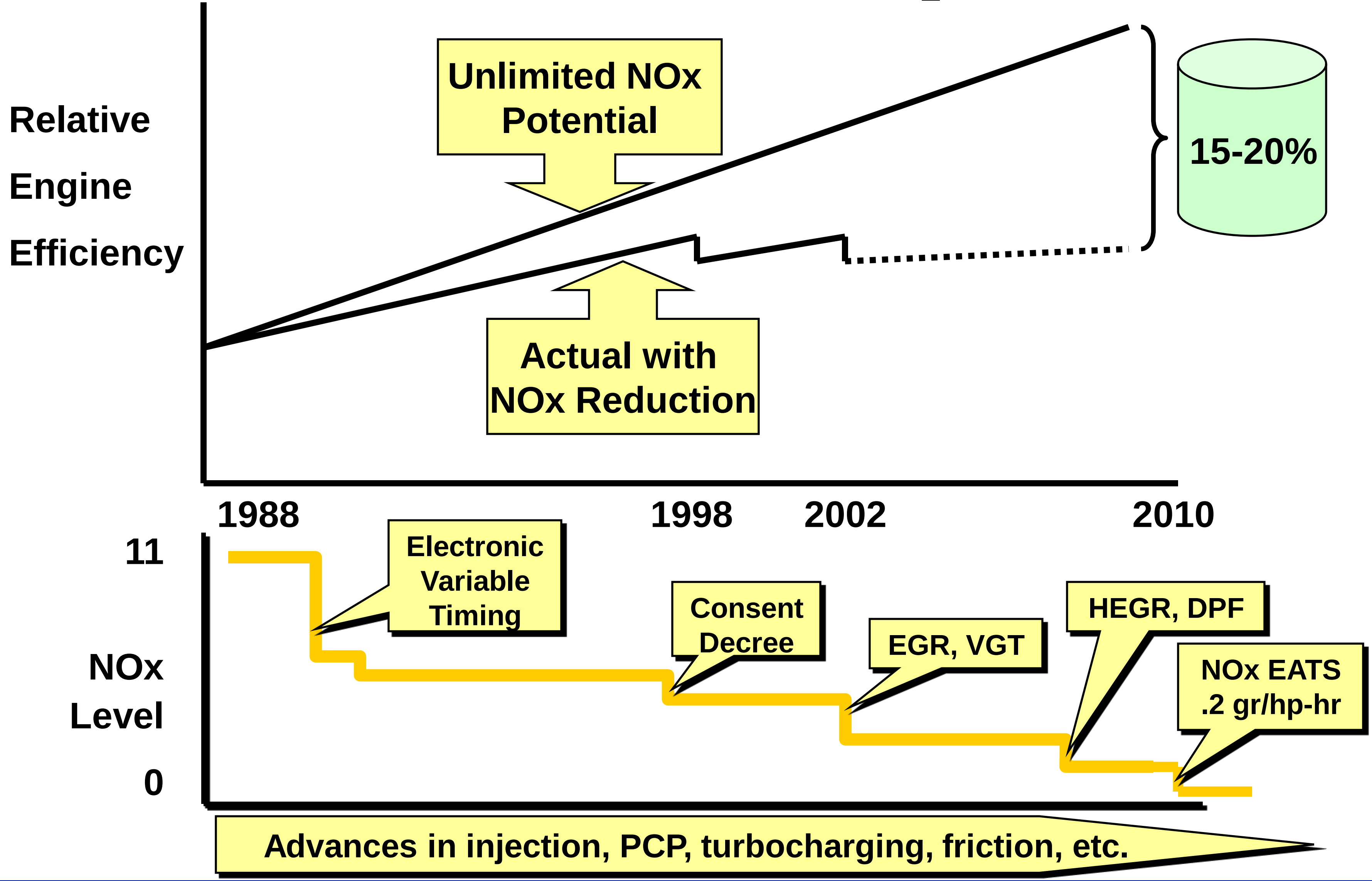
Trailer changes??

- **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

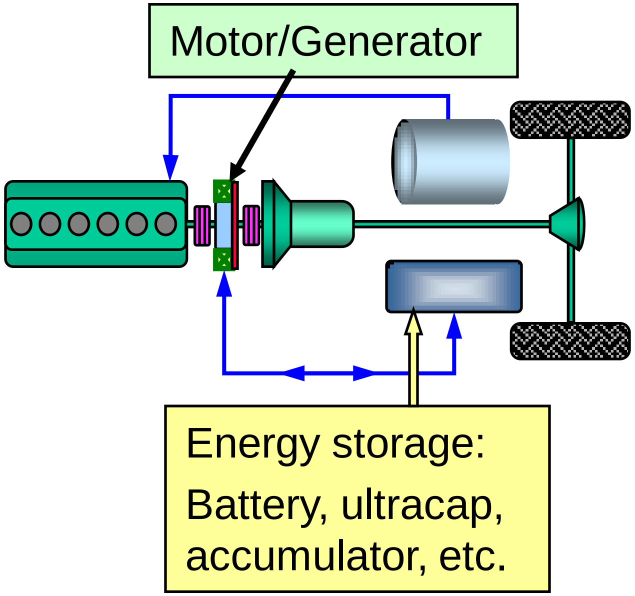
US NOx Reduction Impact on FE



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

Incentives are needed to promote technology introduction until volume is sufficient to lower costs

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)

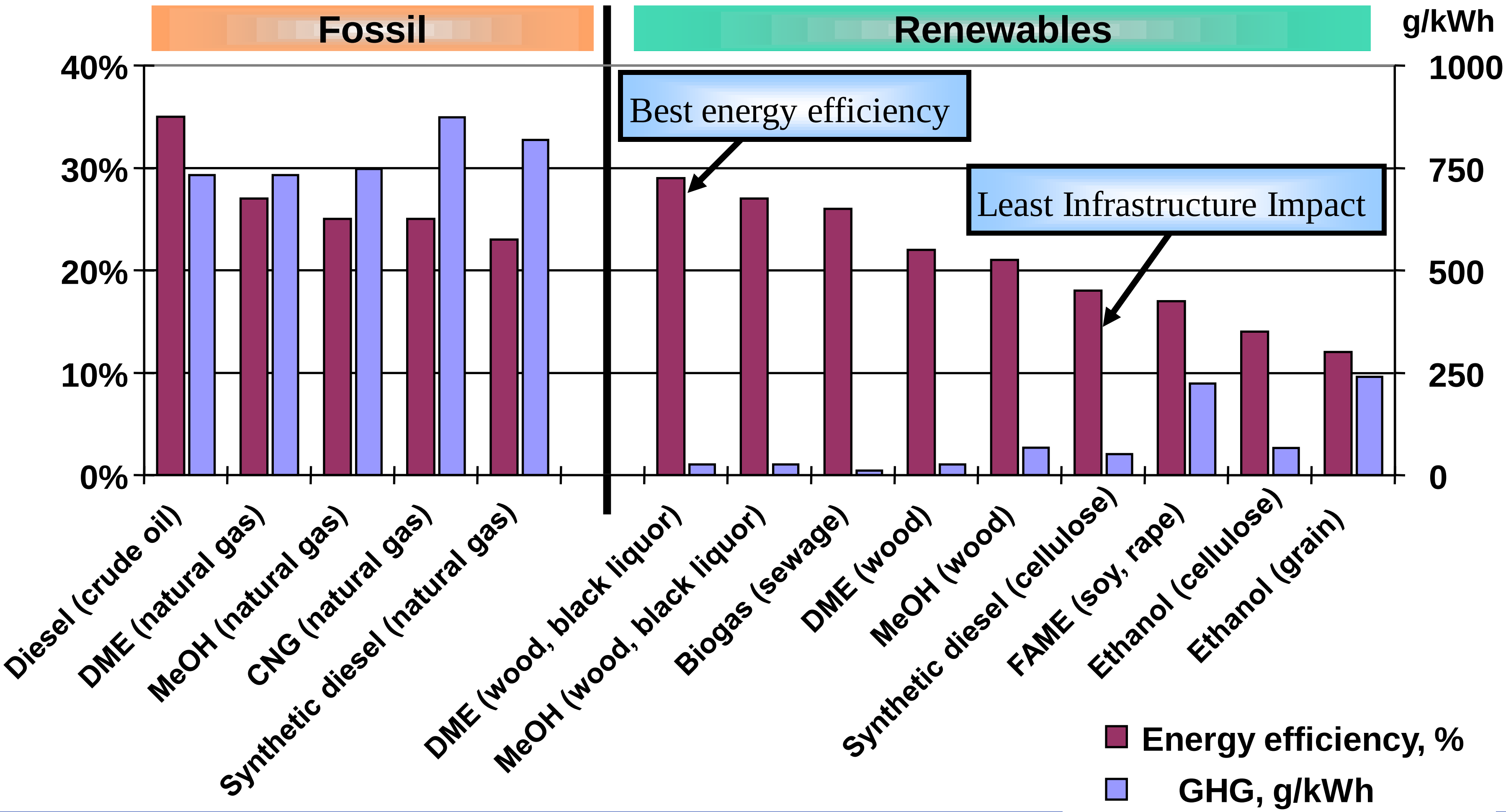
Fuels for the future

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



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

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

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)

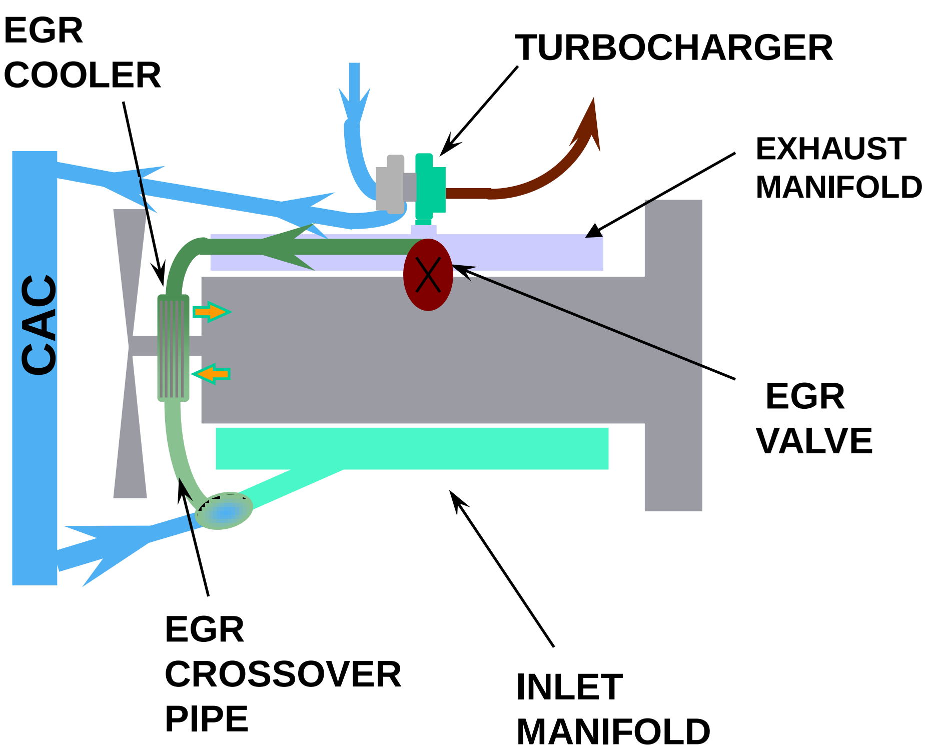
Pumping loss incurred due to EGR flow requirement.

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