

Heavy Duty Truck Technologies for Reducing Fuel Consumption and GHG Emissions



**RETHINKING ENERGY
AND CLIMATE
STRATEGIES FOR
TRANSPORTATION**

ASILOMAR 2011

VOLVO

Powertrain

HD Vehicle Market has Huge Variety Size, Shape, Duty Cycle



Application Impact on Efficiency Technology

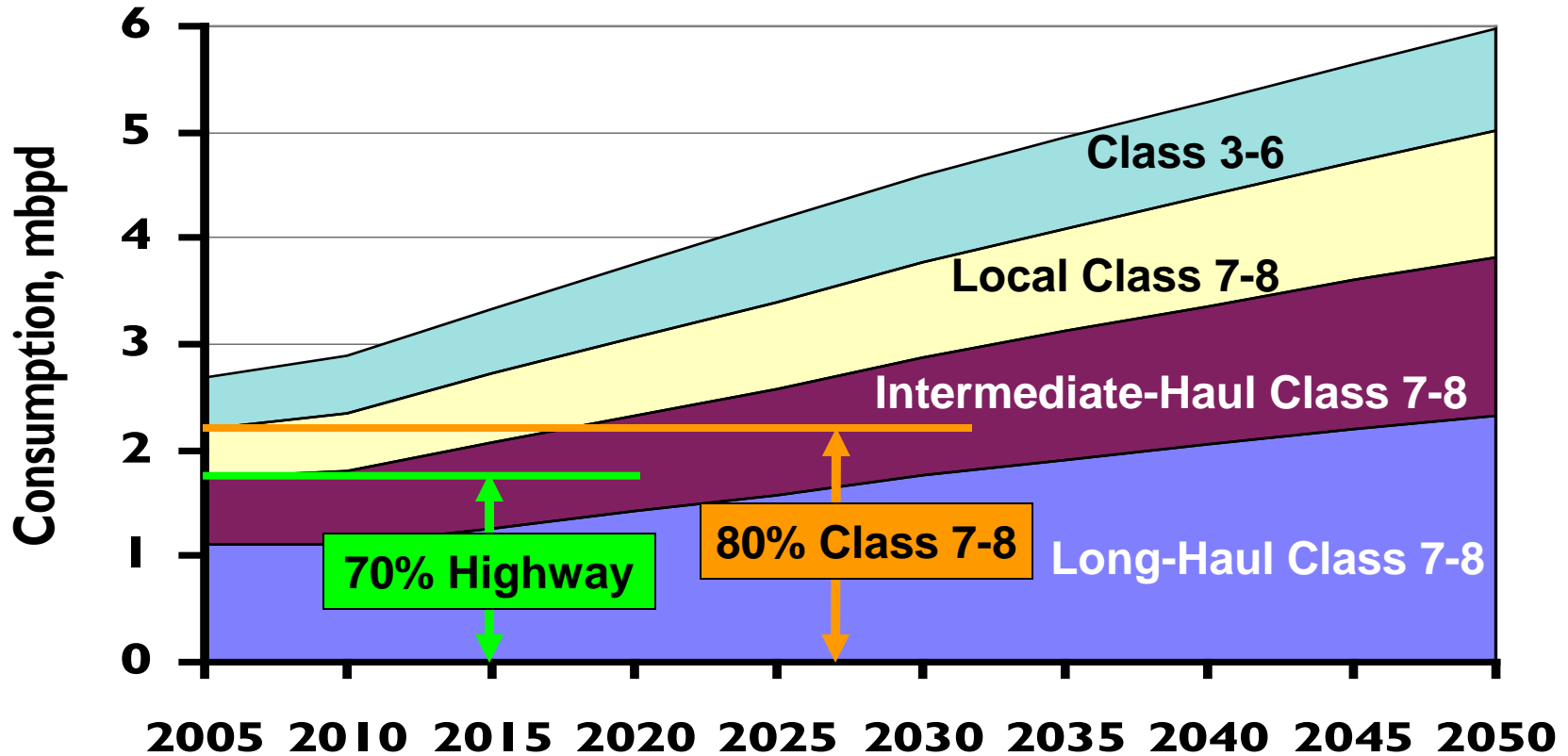


Application	Long Haul	Refuse	Utility - Sweeper
Approximate Power Demand	Aerodynamics – 55%	Aerodynamics – 5%	Aerodynamics – 0%
	Rolling Resistance -30%	Rolling Resistance-20%	Rolling Resistance – 15%
	Auxiliary Devices – 13%	Auxiliary Power – 15%	Auxiliary Power- 85%
	Acceleration – 2%	Acceleration – 60%	Acceleration - 0%

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 Fuel Use for Heavy Trucks through 2050.



Source: US DOE - GPRA 06 FCVT Heavy Vehicle Benefits



**FOCUS
On
Long-Haul**

Light-Duty vs Heavy-Duty Technology

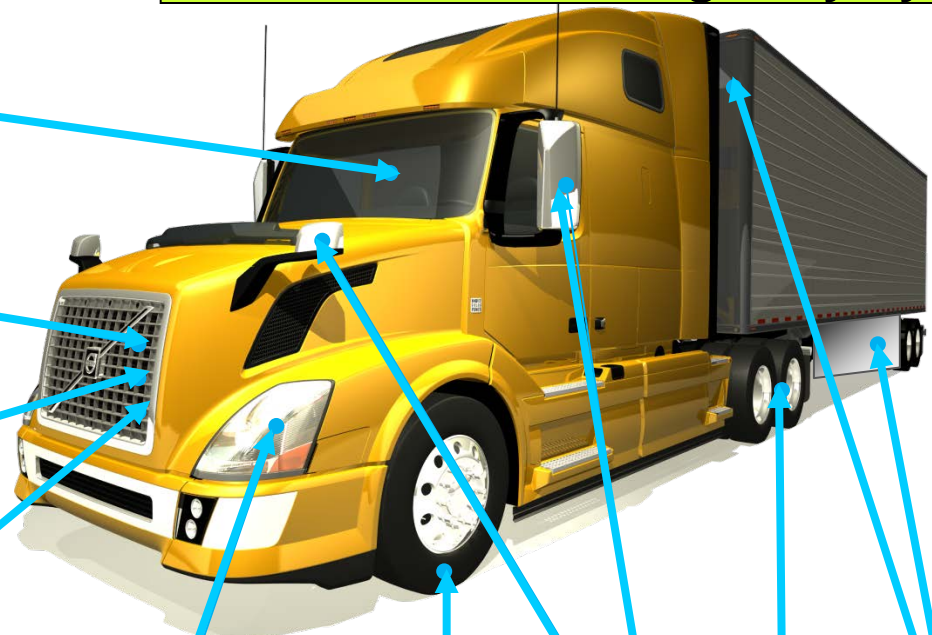


- Most fuel is used to **move the vehicle**
Typically 1.6 passengers & light cargo.
- Heavily used in **urban** areas.
- **Spark** ignited **stoichiometric** engines.
- Key Emerging Opportunities
 - Hybrid
 - Electrification
 - SI engine efficiency or dieselization
 - Ethanol
 - Hydrogen?
 - Reduced weight & Down-sizing

- Most fuel is used to **move cargo** volume and/or weight
- Heavily used on open **highways**.
- **Compression** ignited **lean burn** engines
- Key Emerging Opportunities
 - Integrated aerodynamics
 - Exhaust energy recovery
 - Logistics and vehicle management
 - Bio, renewable, synthetic diesel
 - Natural gas?
 - Longer, heavier- increased capacity

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**

**Energy Efficient
Lighting**

**Low Rolling
Resistance Tires**

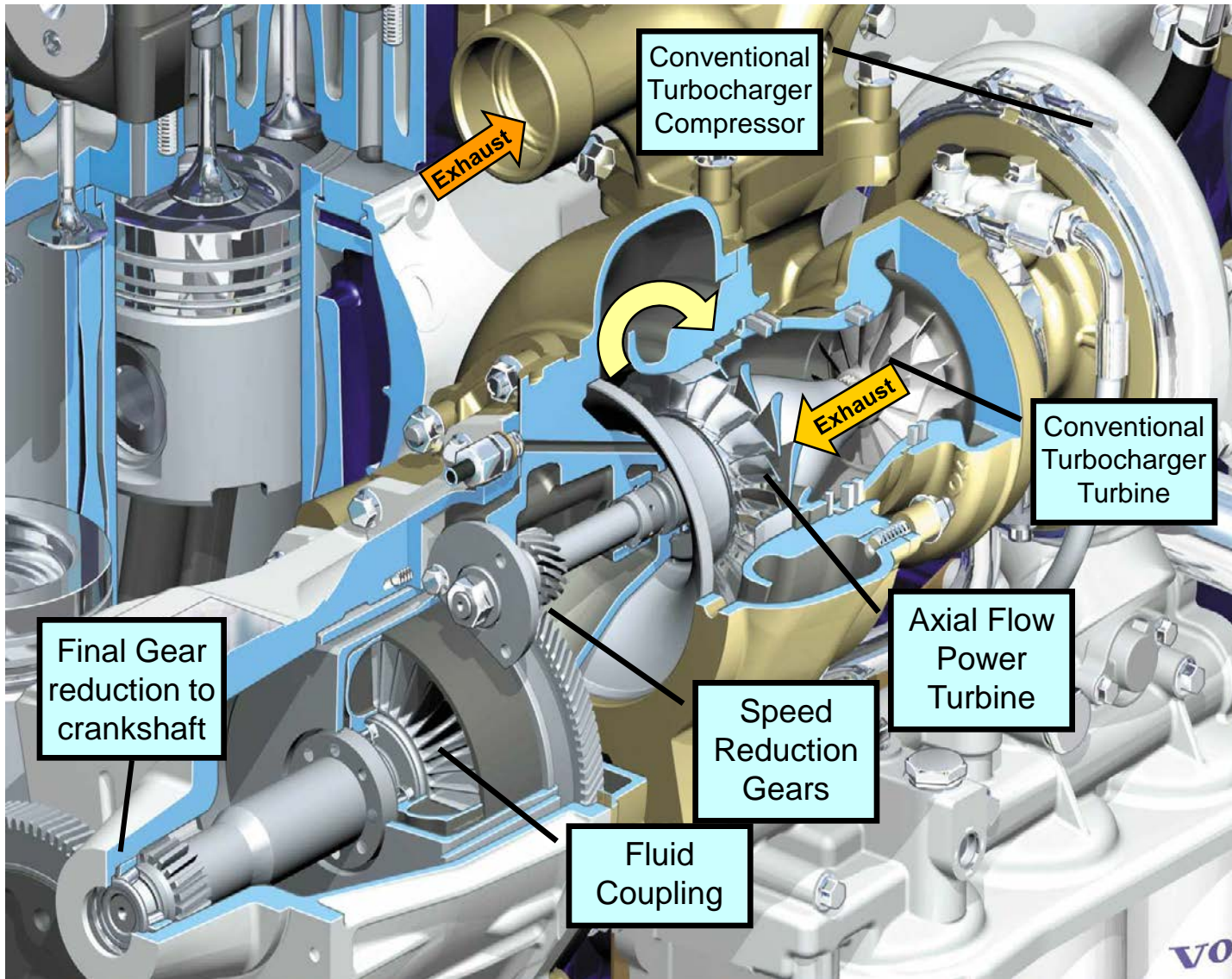
**Improved Tractor
Aerodynamics**

**Smart
Axles**

**Improved Trailer
Aerodynamics**

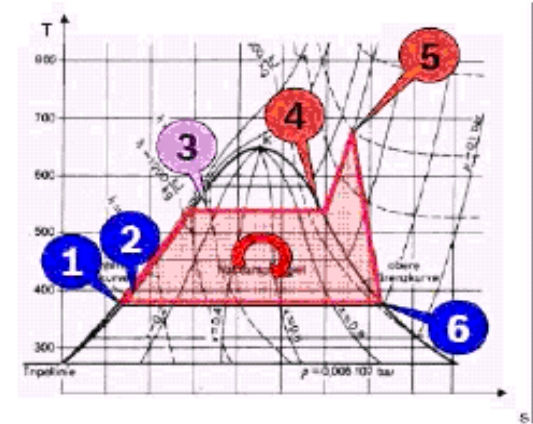
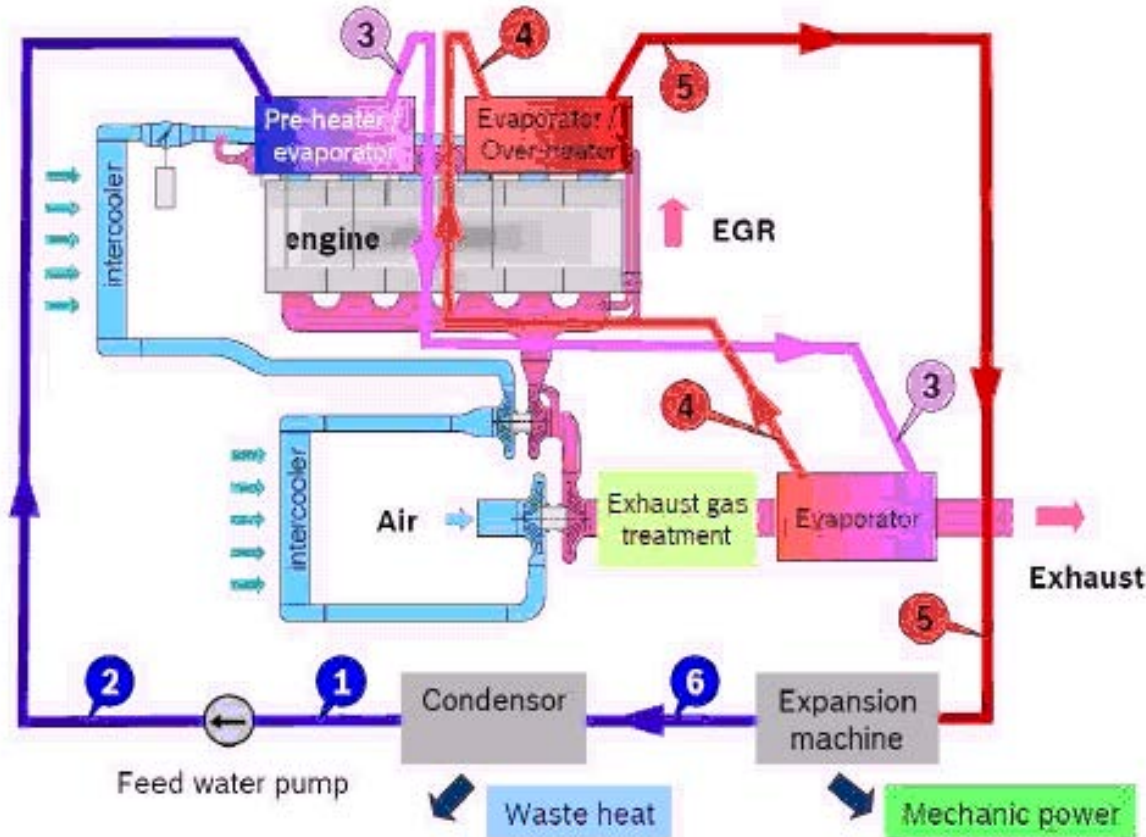
**Hybrid and EV offer significant
potential for urban applications
but not on highway.**

Turbo-Compounding: Essentially a turbine engine added to the diesel



**2 - 4%
Fuel
Efficiency
Benefit in
Long-haul
Application**

Rankine Waste Heat Recovery System: Essentially a steam cycle engine added to the diesel



- 1 → 2: compression, pumping
- 2 → 5: preheating, evaporating, over-heating
- 5 → 6: power generation
- 6 → 1: condensation

Note: complexity, packaging and weight.

Expect 4-5% improved efficiency at US road load conditions.
Maximum efficiency benefit is limited by low temperature heat rejection capability

Key Technology Areas to Improve Long Haul Truck Freight Efficiency

Engines

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

Truck Technology

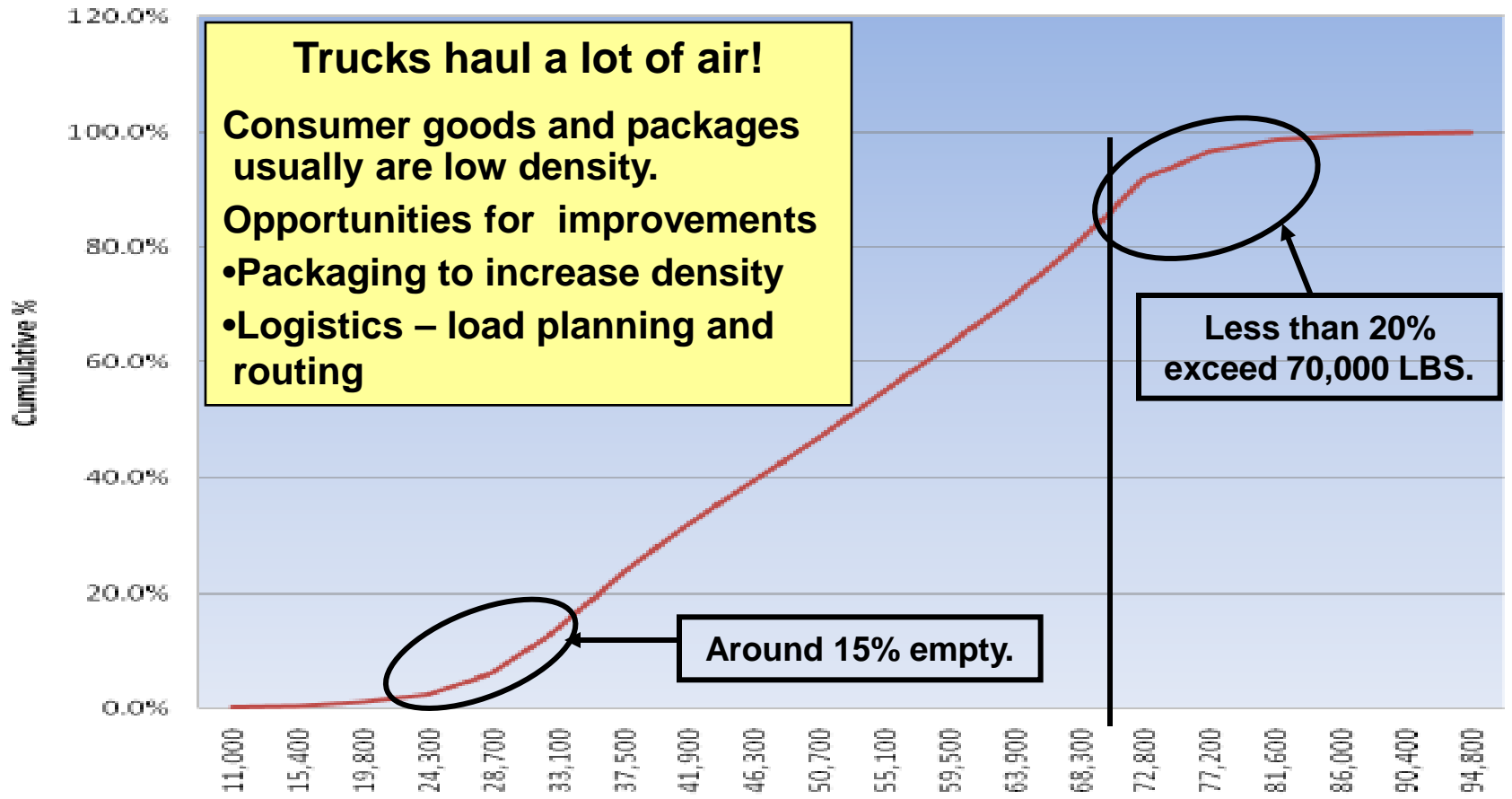
- Smart Transmission & Driveline Efficiency
- Powertrain integration (includes engine)
- Cooling optimization
- Vehicle Auxiliaries (Air comp, PS pump, Air Cond, Fan, Alternator)
- Aerodynamics (tractor)
- Weight
- All Tractor Tires
- Trailer Gap
- Trailer Aero Treatment
- Smart Navigation
- Idle Reduction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

Fleet Operations

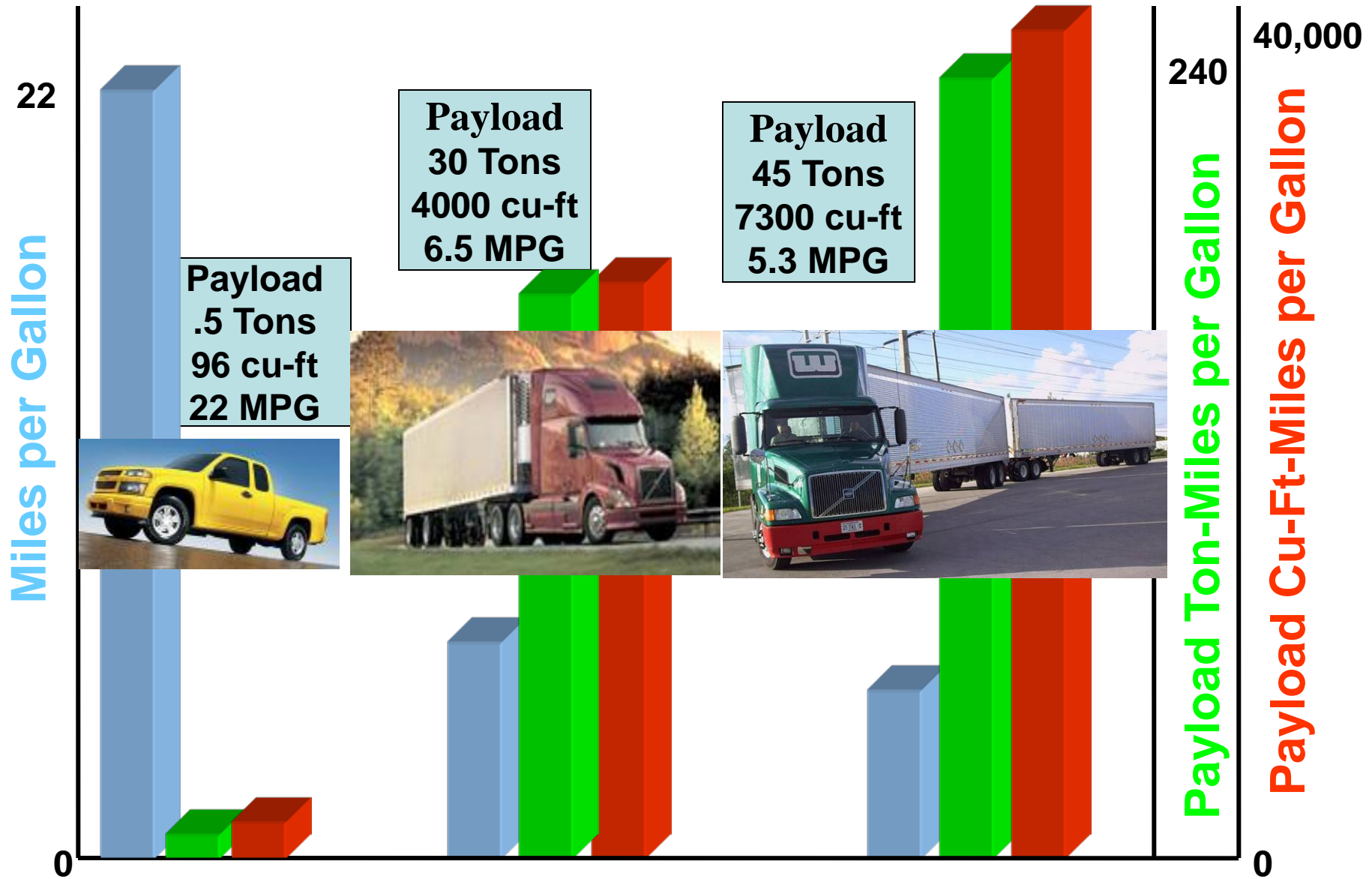
- Logistics
 - Load planning
 - Route Planning
 - Backhauls
- Trailers -Tires, Aero, Weight
- Longer Combinations & increased weight (assuming consistent state regulations)
- Intermodal (rail)
- Driver Training
- Trailer gap control
- Idle Elimination
- Road speed reduce 7 MPH

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.

Cumulative Percentage of 5-Axle Tractor Trailer Combination Vehicles by Gross Vehicle Weight as Reported by VTRIS for Fifteen States (CA, CT, FL, GA, HI, IA, MN, MO, MT, NC, MN, OR, PA, SD, TX, & WA) in 2008

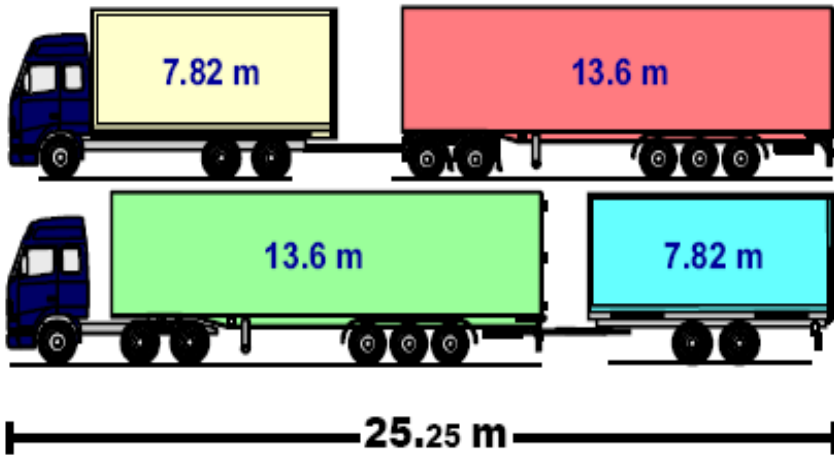


Larger Vehicles Move Freight More Efficiently



Longer Combination Trucks

Single Biggest Potential Efficiency Gain via Lower VMT



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.

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

6-axle Tractor-Semitrailer



Rocky Mountain Double (RMD)



Triple Trailer Combination (TRPL)

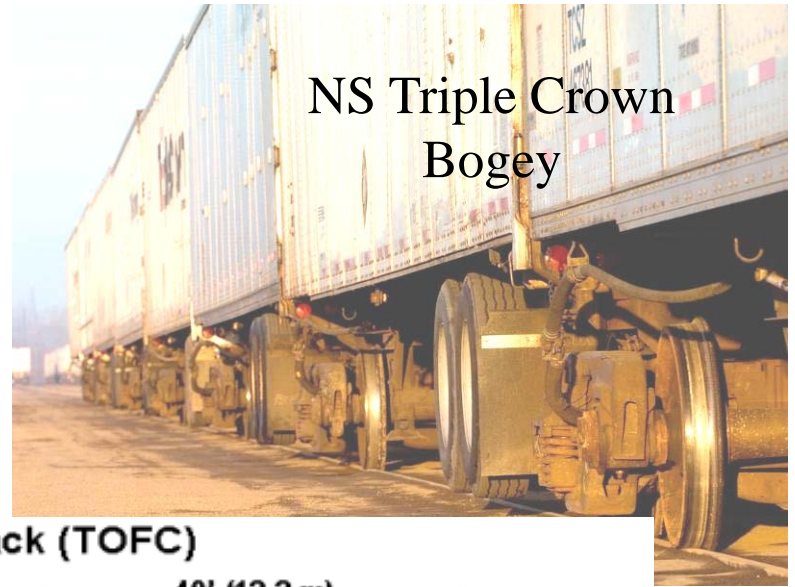


Turnpike Double (TPD)

Port Truck In Sweden

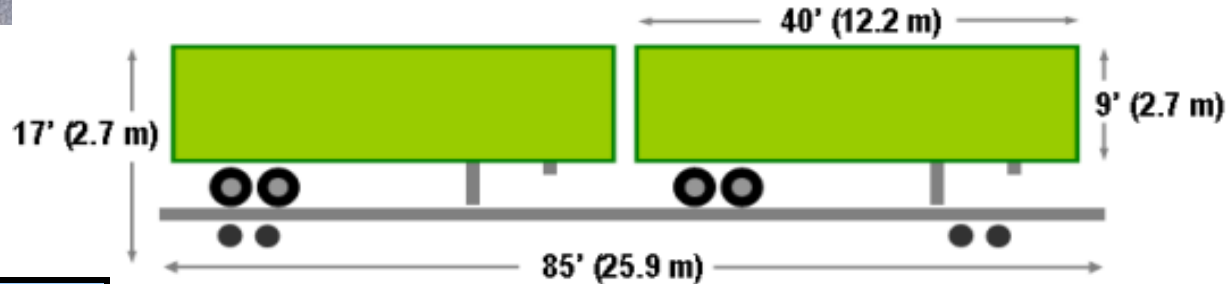


Increase Intermodal Truck-Rail

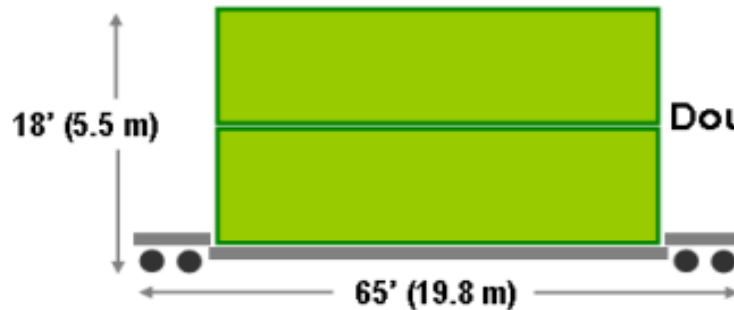


NS Triple Crown Bogey

Piggyback (TOFC)

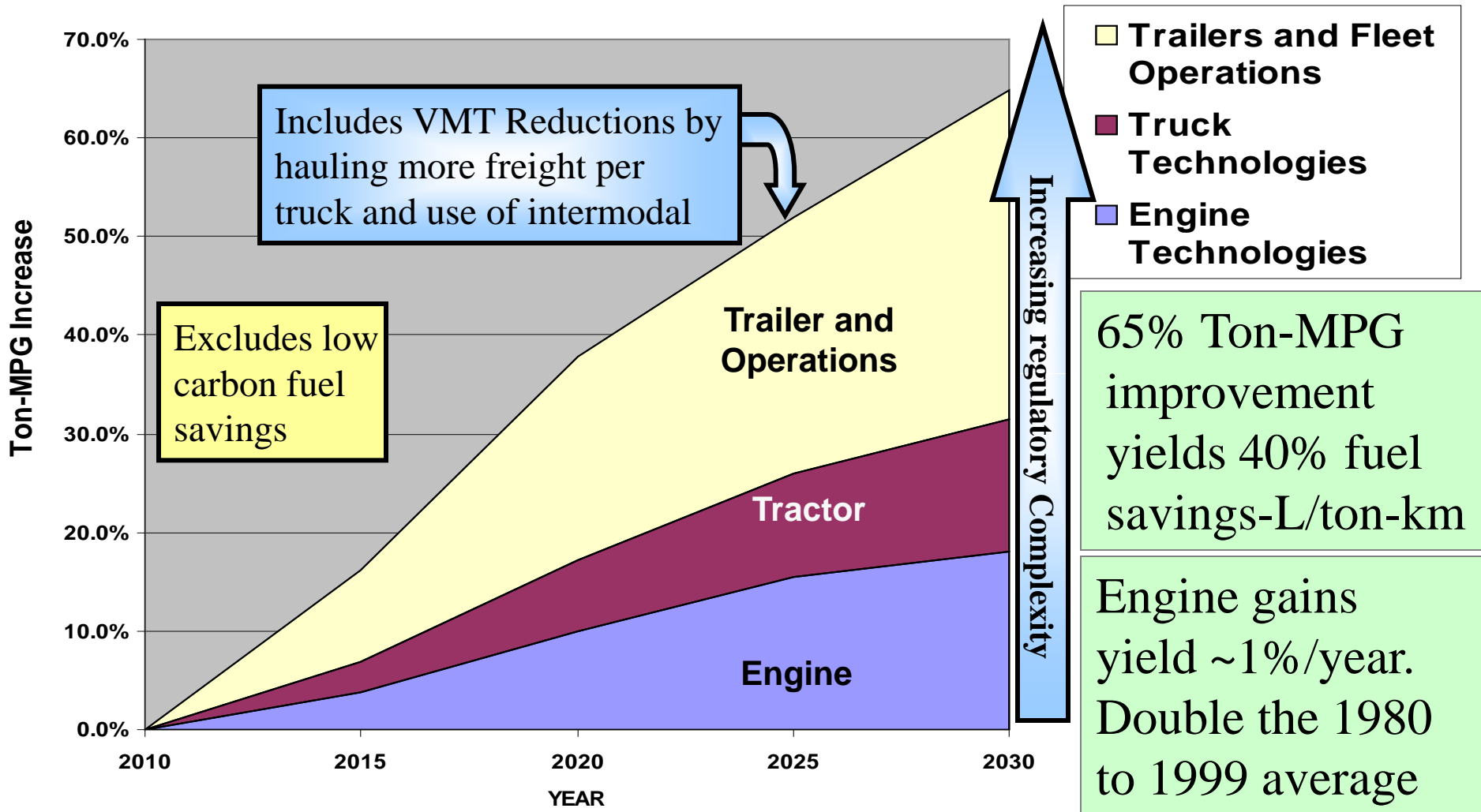


Doublestack (COFC)

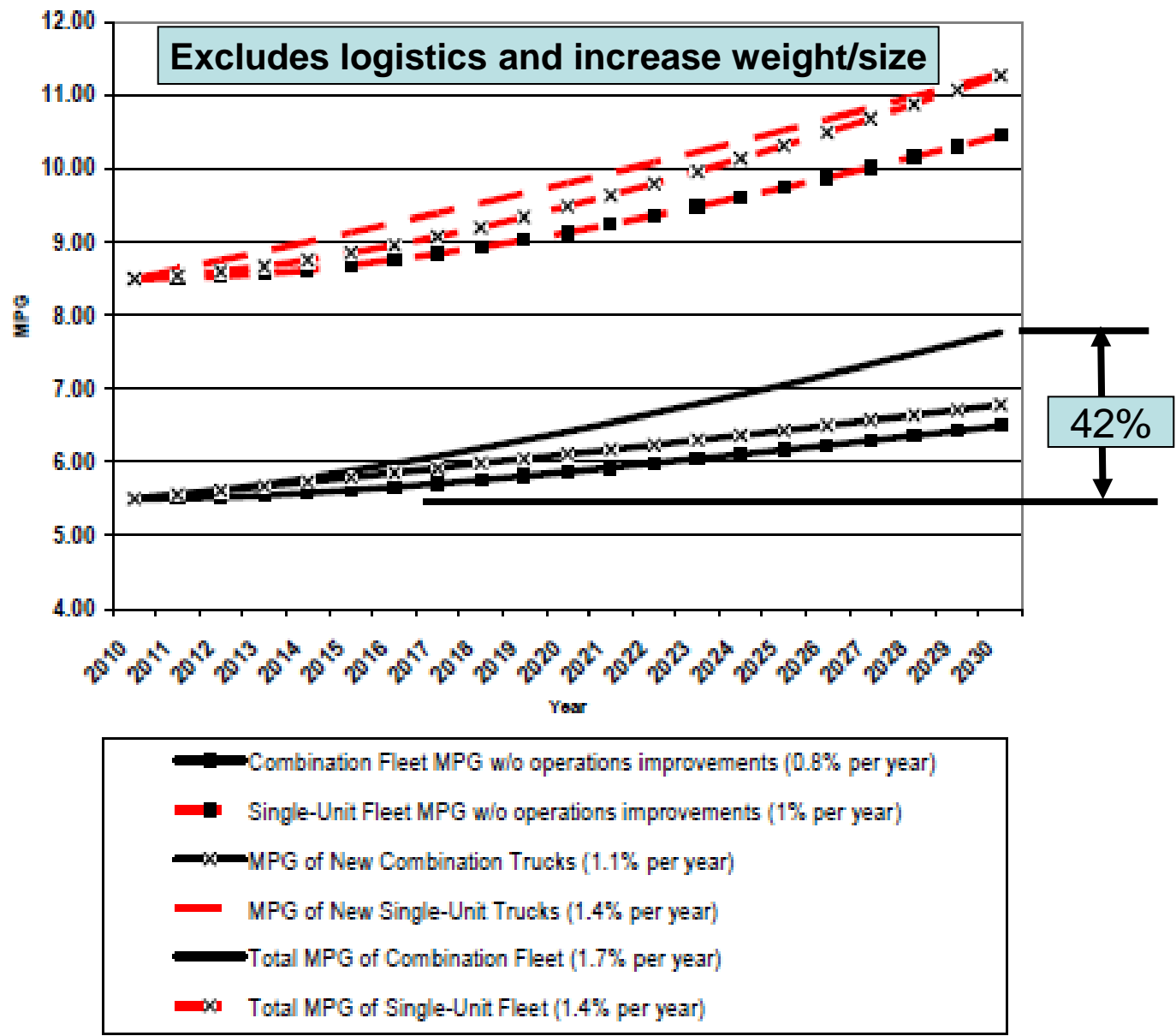


Estimated Fuel savings of around 50% but need better study.

Class 8 Ton-MPG - A Prospective Scenario Via Vehicle Efficiency Gains and VMT Reductions



**TRB
Projections
for Truck
Fuel
Economy
Through
2030**



Source: Transportation Research Board Special Report 307

“Policy Options for Reducing Energy Us and Greenhouse Gases from US Transportation”

CO2 Reduction through Bio-fuels?

- Renewable fuel alternatives are possible
- But many arguments about GHG efficacy and impact on food supply.

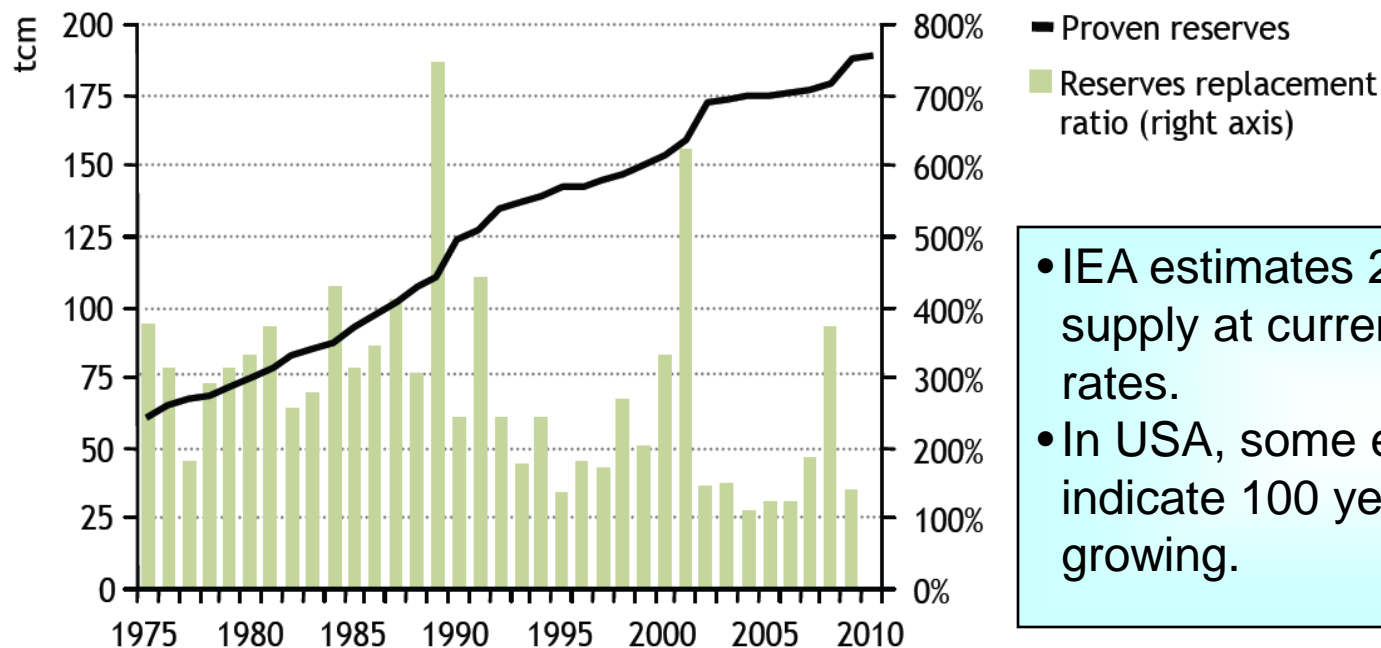
Indirect Land Use and GHG Impact?



Natural Gas in Trucks?

- Driver for NG vehicles is shifting from primarily environmental concerns to economic and fuel security concerns.
- Proven domestic reserves of NG have grown dramatically due to shale gas extraction via fracturing.

Figure 2.2 ▸ Evolution of world proven natural gas reserves

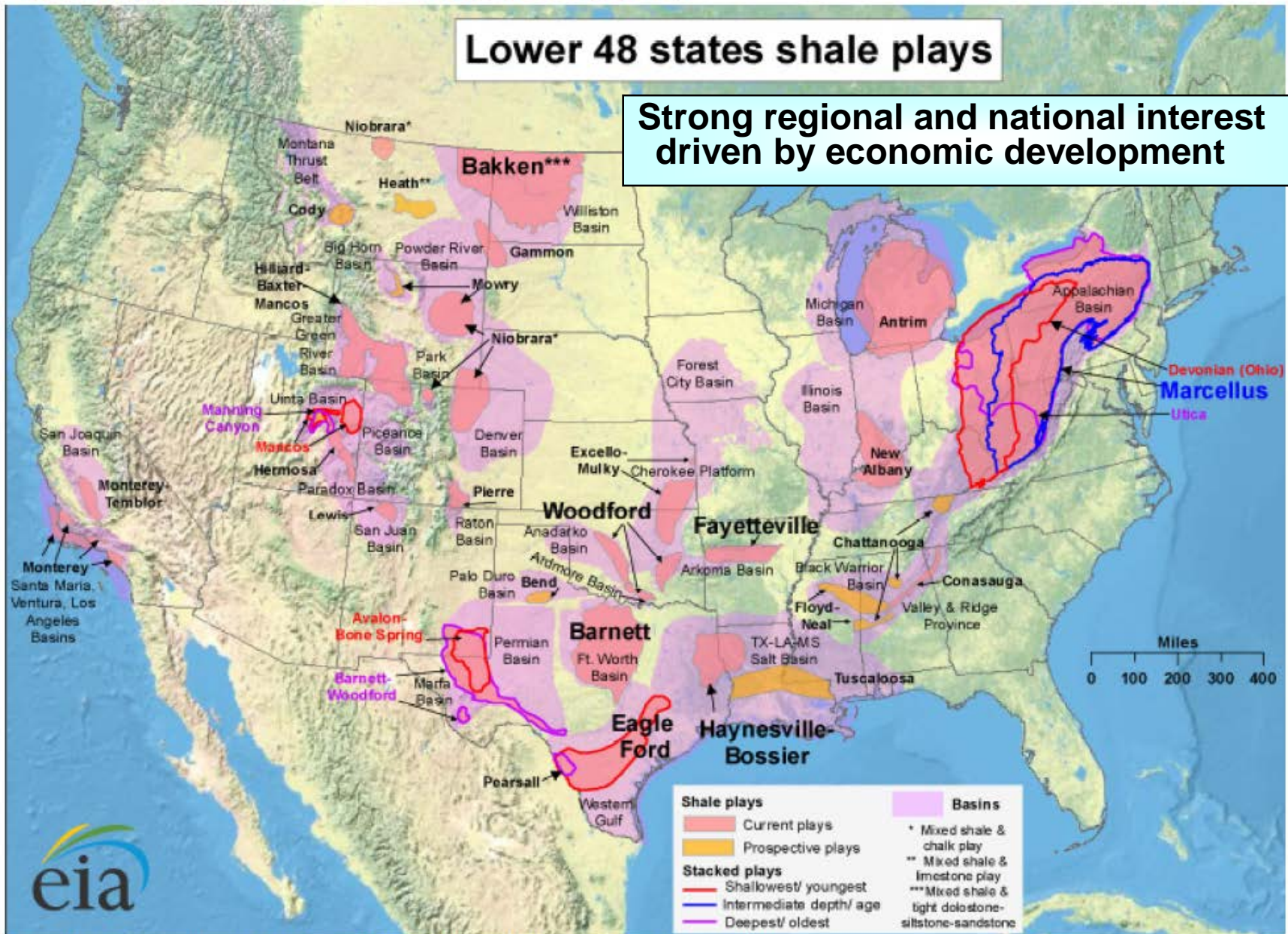


- IEA estimates 250 years global supply at current consumption rates.
- In USA, some estimates indicate 100 year supply and growing.

Note: Reserves replacement ratio is gross reserve additions divided by annual production. Proven reserves are net volume at the beginning of the year.

Sources: Cedigaz (2010); IEA databases.

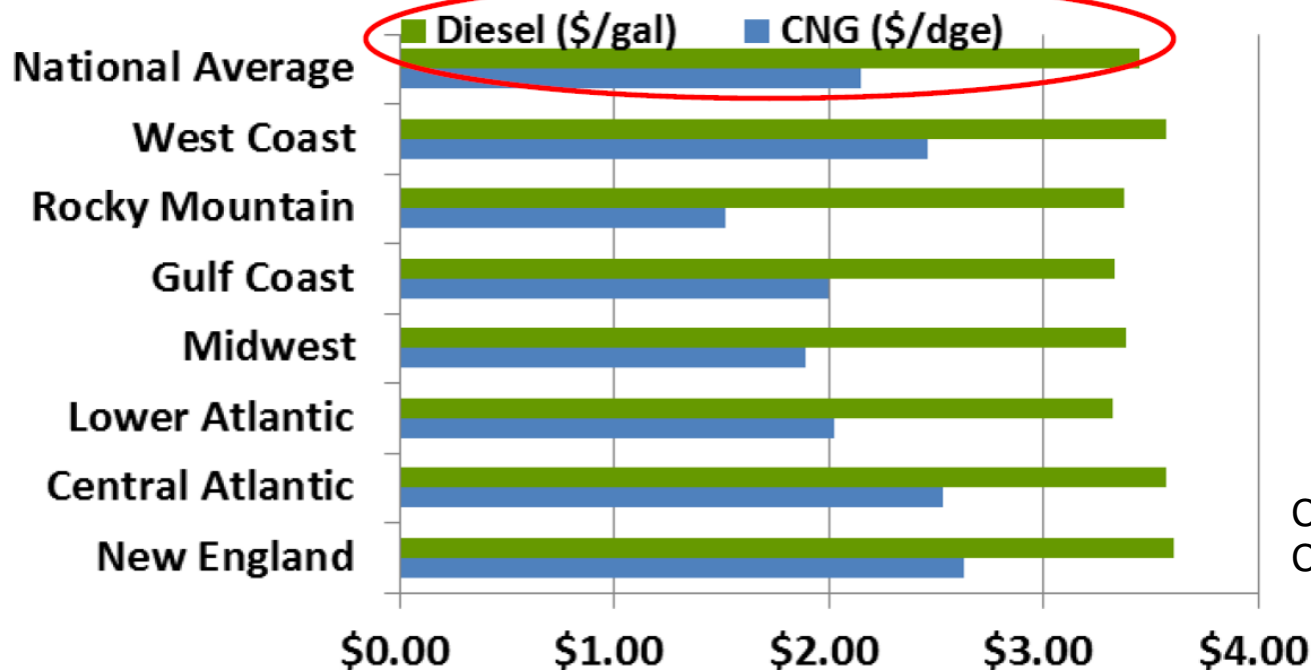
Figure 1. Map of U.S. shale gas and shale oil plays (as of May 9, 2011)



Source U.S. Energy Information Administration based on data from various published studies.
 Update: May 9, 2011

NG Motor Fuel Cost

- NG cost per DGE (diesel gallon equivalent) is significantly lower than diesel
- LNG is required for long-haul operation. CNG has inadequate range.
- Vehicle cost is typically 40% higher than for diesel. But mostly due to low volume production.
- Sustained fuel cost differential is creating market pull for NG fueled vehicles.
 - All major truck OEM's now offering NG trucks.
 - Growing volume will lower vehicle cost - further increasing demand
 - High diesel price is key to NG growth

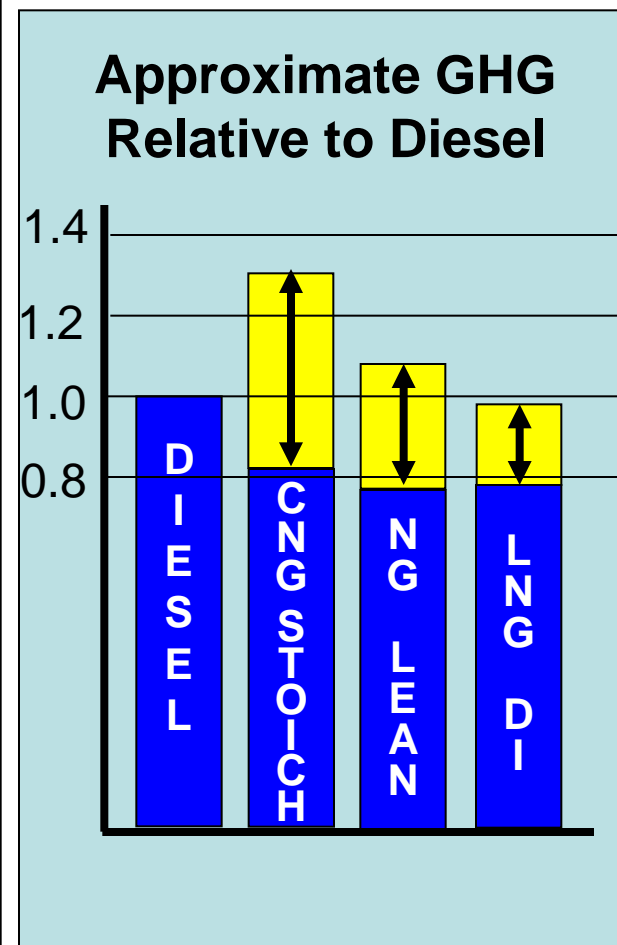


**LNG cost was
\$2.40 - \$3.00
per DGE as of
July, 2011.**

CNG cost data from
Clean Cities, June, 2011

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

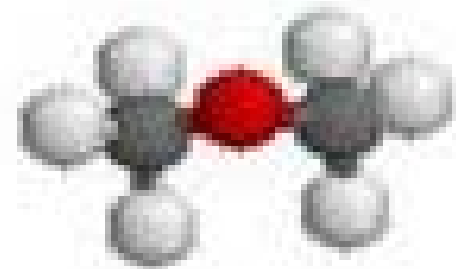


Natural Gas Conclusions

- Sustained fuel cost differential will likely drive the commercial market.
- Immediate potential GHG benefit of approximately 15%
 - Need focus on efficiency in fuel production and engine to realize GHG benefits
 - Need to evaluate and improve engine technologies
 - Should consider alternate pathways to use NG like DME
- Political Drivers
 - Energy security
 - Imported petroleum displacement
 - Regional economic stimulus
- Long Term Impact
 - Cumulative GHG savings as volume grows
 - Low cost NG may delay other alternatives
 - Venting of CH₄ from older LNG vehicles may become a problem (CH₄ has 25 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



Dimethyl Ether



Issues & Opportunities for Road Freight Efficiency

- **Highly complex and expensive technologies must be supported by long-term, predictable ROI and/or forced by regulation.**
- **Regulation is complex with significant potential unintended consequences.**
- **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
- **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
- **Infrastructure**
 - Highway infrastructure and Intelligent Systems
 - 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

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.**
- **We lack 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.**