The Role of the Internal Combustion Engine in our Energy Future

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VOLVO

Powertrain

Volvo Organisation

AB Volvo

Business Areas

- **Mack Trucks**
- **Renault Trucks**
- **Volvo Trucks**
- **BA Asia** Incl. UD Trucks
- **Buses**
- **Construction Equipment**
- **Volvo Penta**
- **Volvo Aero**
- **Financial Services**

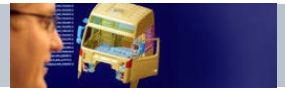
Business Units

Volvo 3P

Volvo Powertrain

Volvo Parts

Volvo Logistics



Volvo Information Technology & Others

HD Vehicle Market has Huge Variety

Size, Shape, Duty Cycle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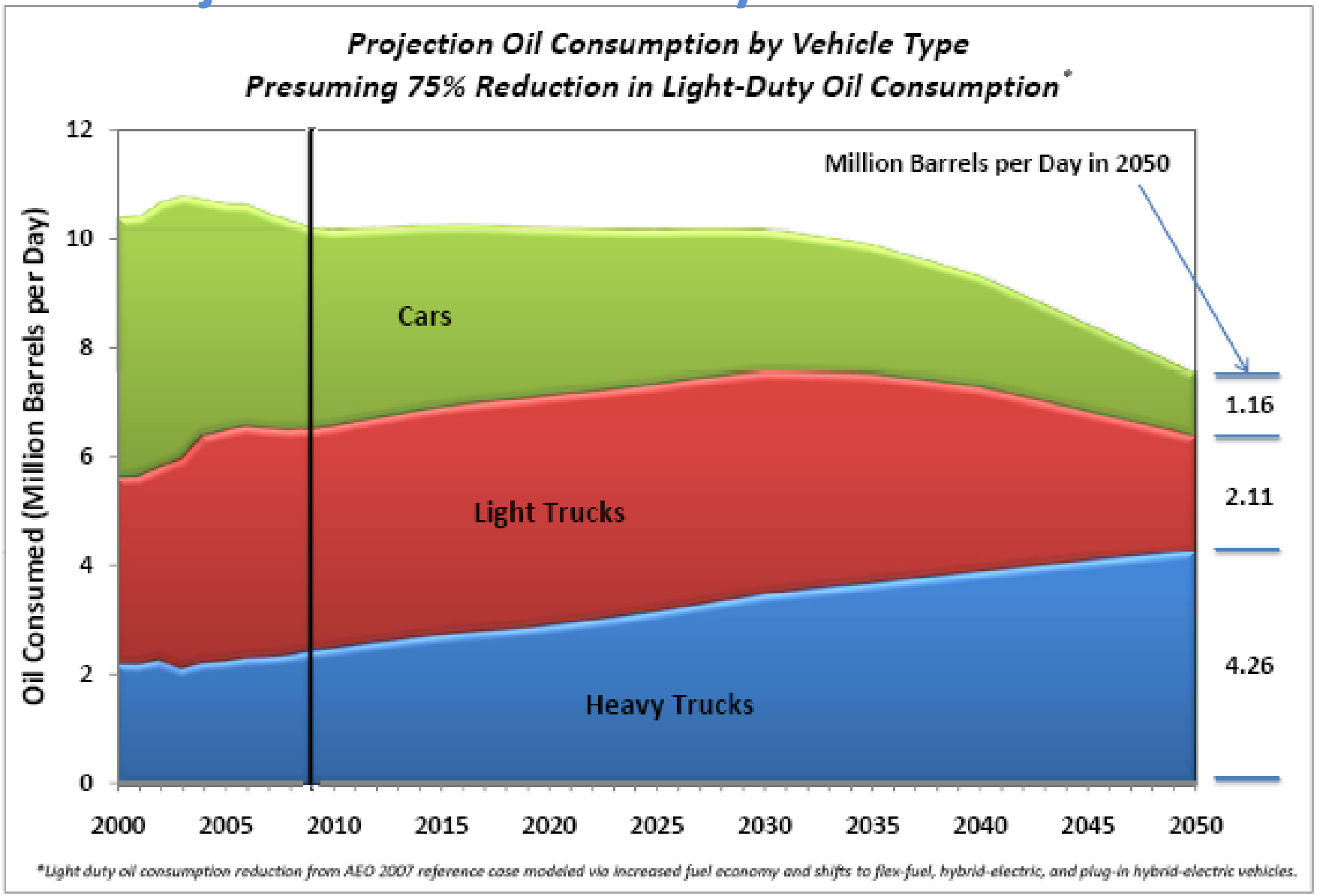
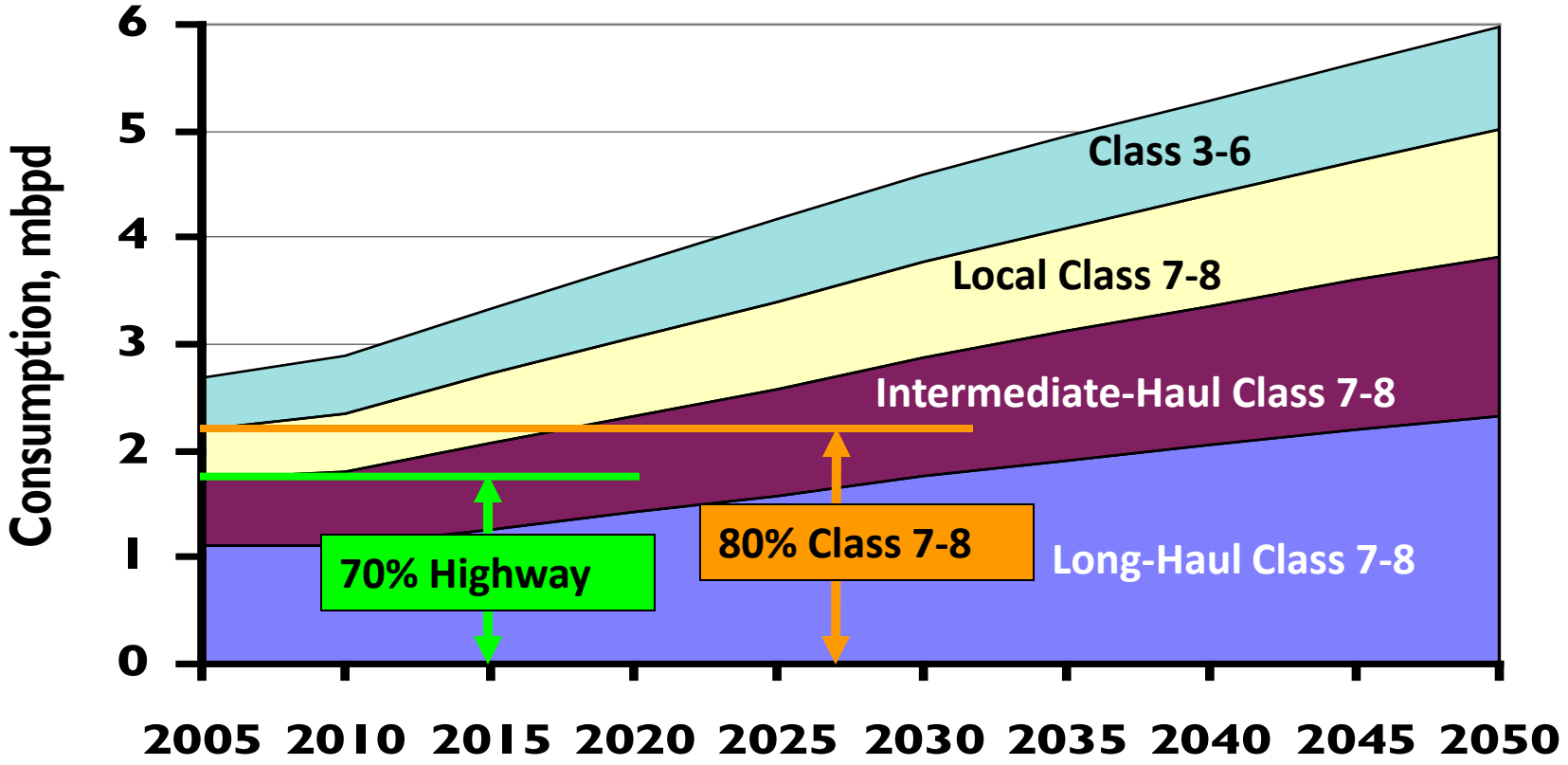
Projection – Provided by US DOE in 2009



Projected Fuel Use for Heavy Trucks through 2050.



Source: US DOE - GPRA 06 FCVT Heavy Vehicle Benefits

FOCUS
On Class 8
Long-Haul

Factors Influencing Power Choices for Motor Vehicles

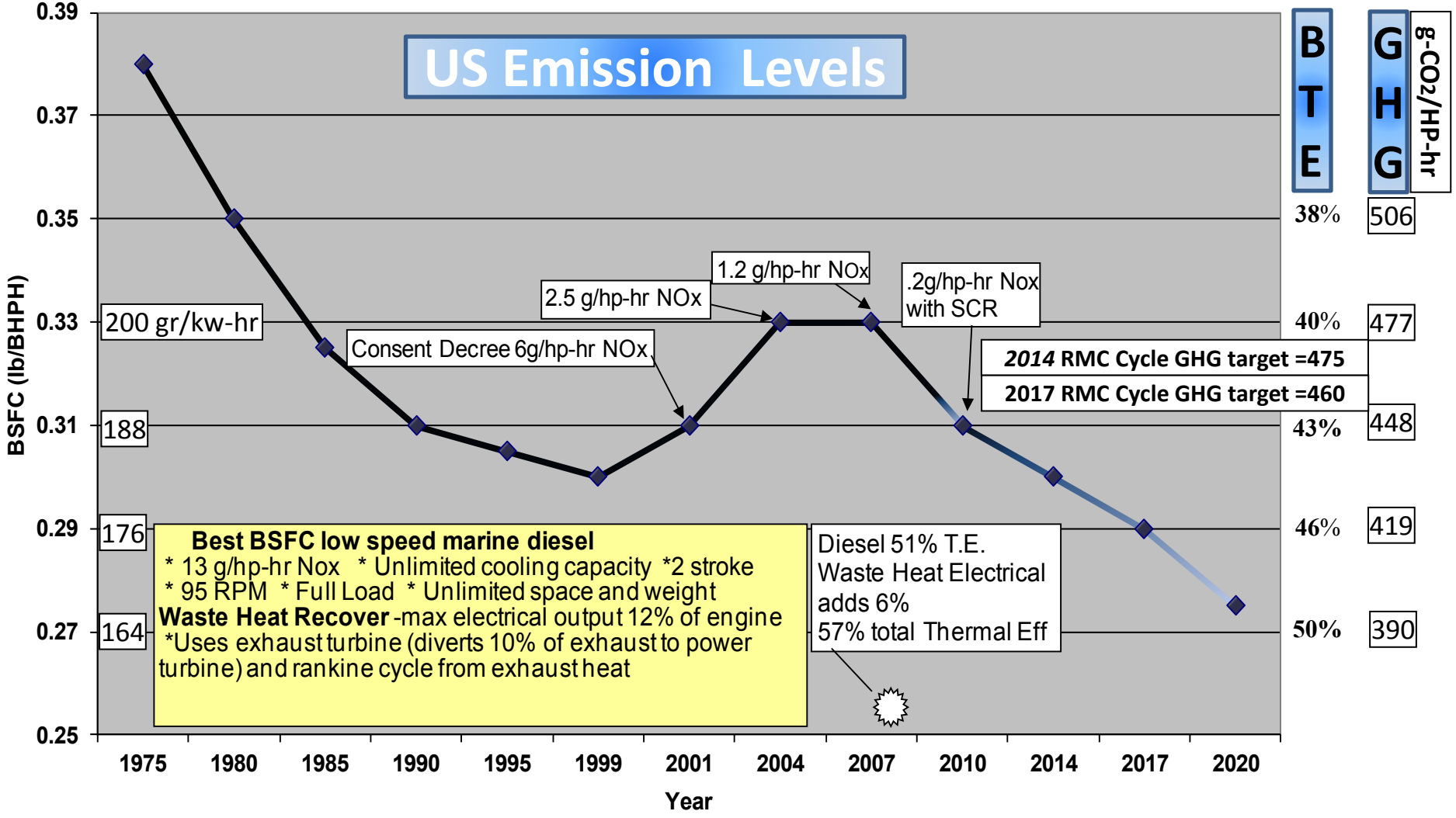
- Power Demand Requirements
- Fuel Availability
- Durability
- Reliability
- Operating Cost
- Acquisition Cost
- Emissions
- Range with on-board fuel
- Size
- Weight
- Response lag time
- Cooling Requirements
- Refueling time

Factors Driving Potential ICE Replacement

- Finite supply of fossil fuel
  - -Cost Impact
- GHG emissions
- Energy security
- Better alternatives?

Driving Factors all Relate to Fuel Issues

Historical & Projected HD US Diesel Efficiency



Alternatives to ICE's

- **Gas Turbine**
- **Rankine**
- **Sterling**

Don't really address the problem unless they provide substantial improved efficiency

- **BEV**
- **Fuel Cell**
- **Other?**

Gas Turbine?

- **Efficiency challenged to get above 40% in mobile applications.**
- **Efficiency suffers at light load compared to diesel**
- **Slow response**
- **Expensive – even compared to full diesel emissions package**
- **Might be an option in hybrid combination**
- **But doesn't offer a real advantage over diesel ICE**

Figure 6 VT300 Engine left side

Rankine Engine?

- **Has been around a long time in various forms**
- **Recent incarnations may be feasible for on-road motor vehicles**
- **Still doesn't approach diesel efficiency targets**
- **Greater fuel flexibility may offer some opportunity**
- **Still no indication that it will become a significant player in motor industry**

Sterling Engine?

- Never a strong consideration for motor vehicles
- Bulky
- Slow responding
- Materials limit operating temperature and efficiency
- Practical efficiency does not approach diesel

PEM or SOFC Fuel Cell?

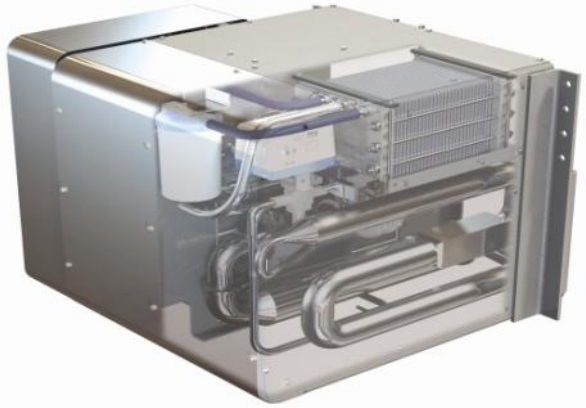
PEM is 50-60% EFFICIENT

- **45% of fuel energy must be extracted by coolant at temperatures around 70-80C.**
- **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**

Battery requirements for electric propulsion

10 kg for 10 km Possible!

40 kg for 10 km Possible!

200 kg for 10 km Possible!

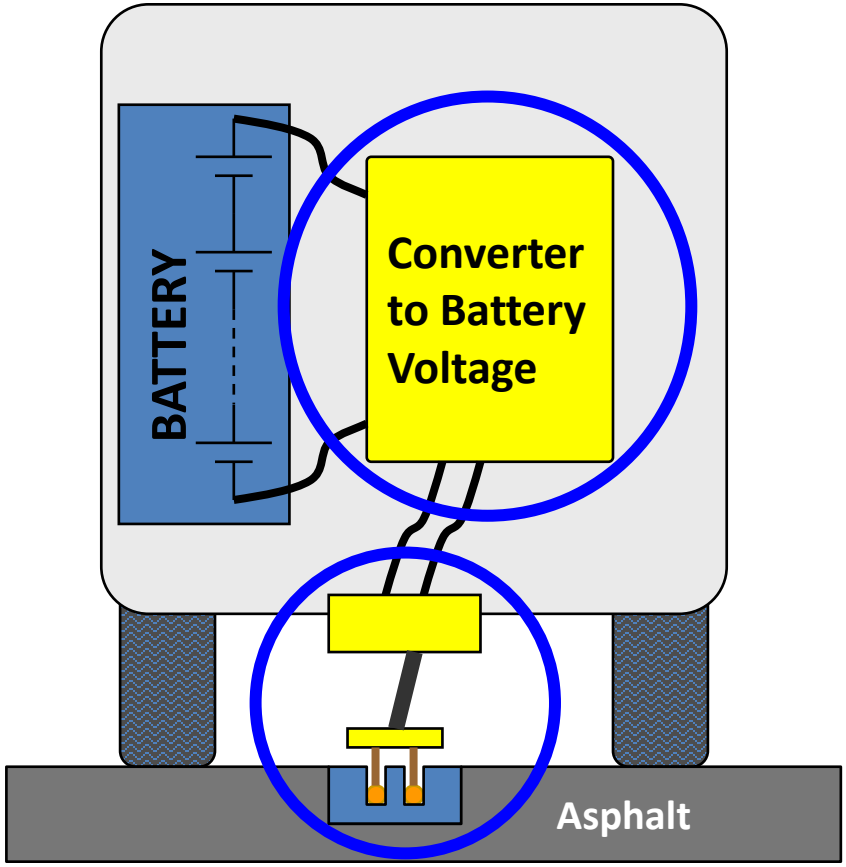
20 tons for 1000 km
Not possible!

45 000
The tal
tons ! I

Battery operation alone not possible for Long Haul/Coach …

One possible Full Electric Option…

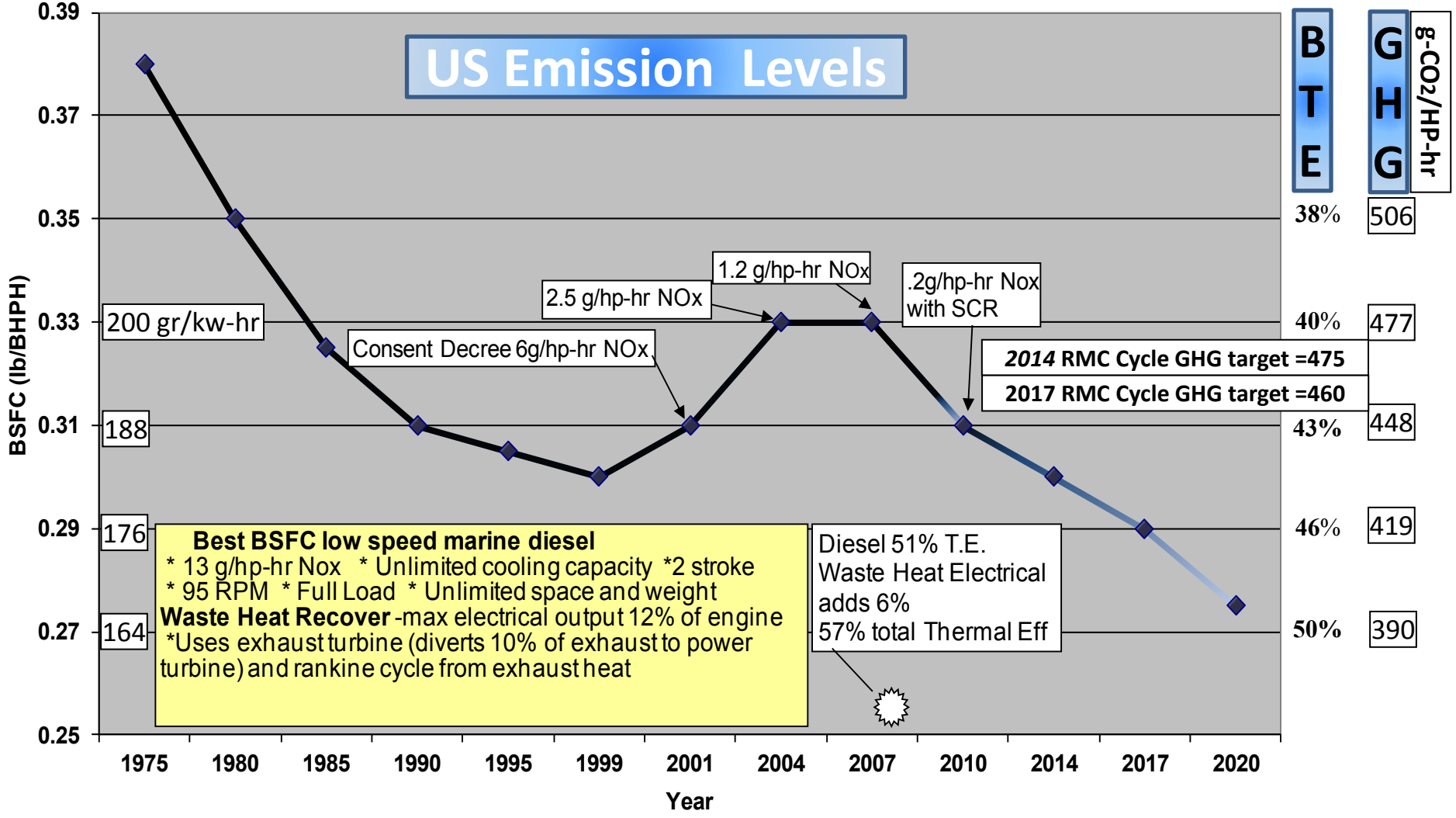
- A Plug In vehicle able to charge from a "Slide In" track in the road
- Can REALISTICLY reduce the Energy Use by 50 % (Long haul) up to 75 % (Cars)
- Almost eliminates the use of fossil fuel
- Does not require any Rocket Science and can have realistic safety
- But requires development of safe and reliable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



Where does that leave us?

- Diesel cycle engines will be prime movers for freight transport for a long time
  - This means compression ignition, not necessarily diesel fuel
- Vehicle electrification (where feasible) and efficiency improvements should be applied as broadly and quickly as possible
- Fossil and biofuels should be reserved for long-haul transport and industrial feedstocks that don’t have alternatives.

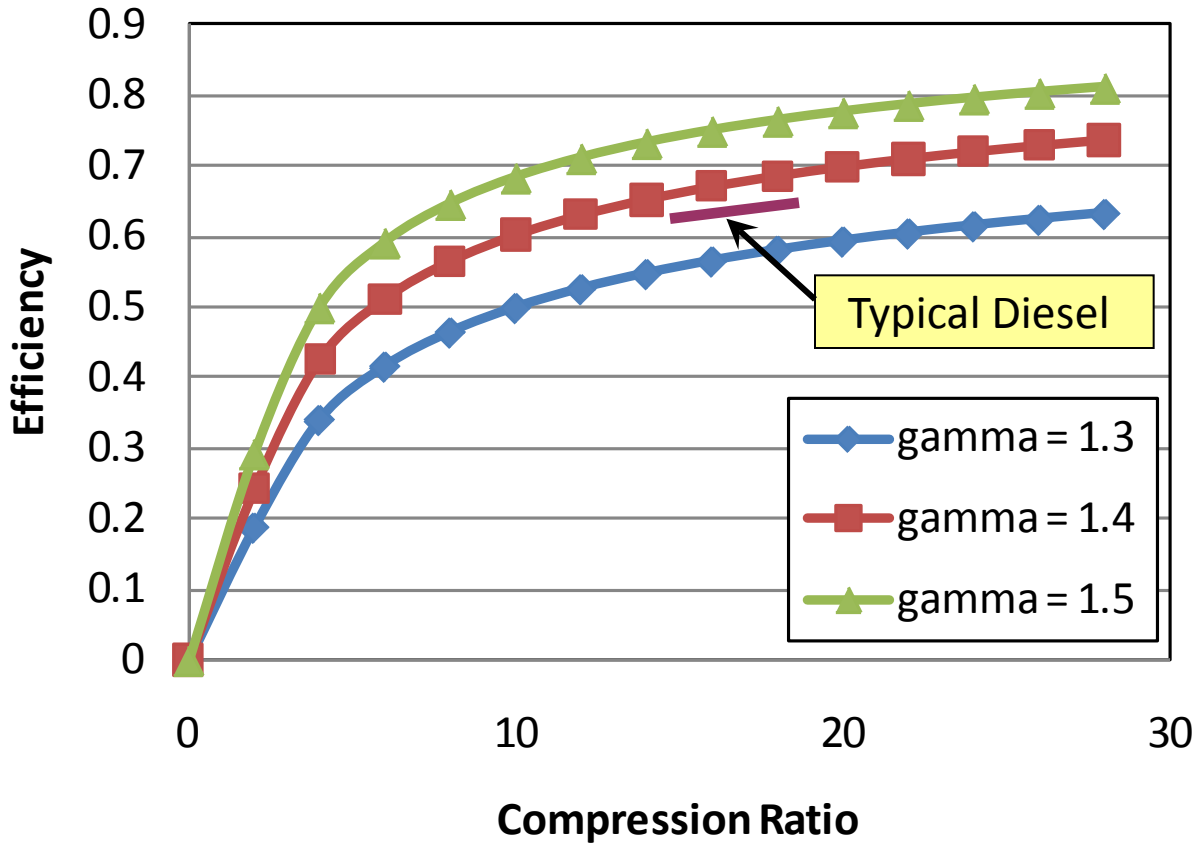
So, how do we achieve these efficiencies?



Back to Basics…

- Air-Standard Otto-Cycle

$$\eta_{otto,th} = 1 - \frac{1}{r^{\gamma-1}}$$



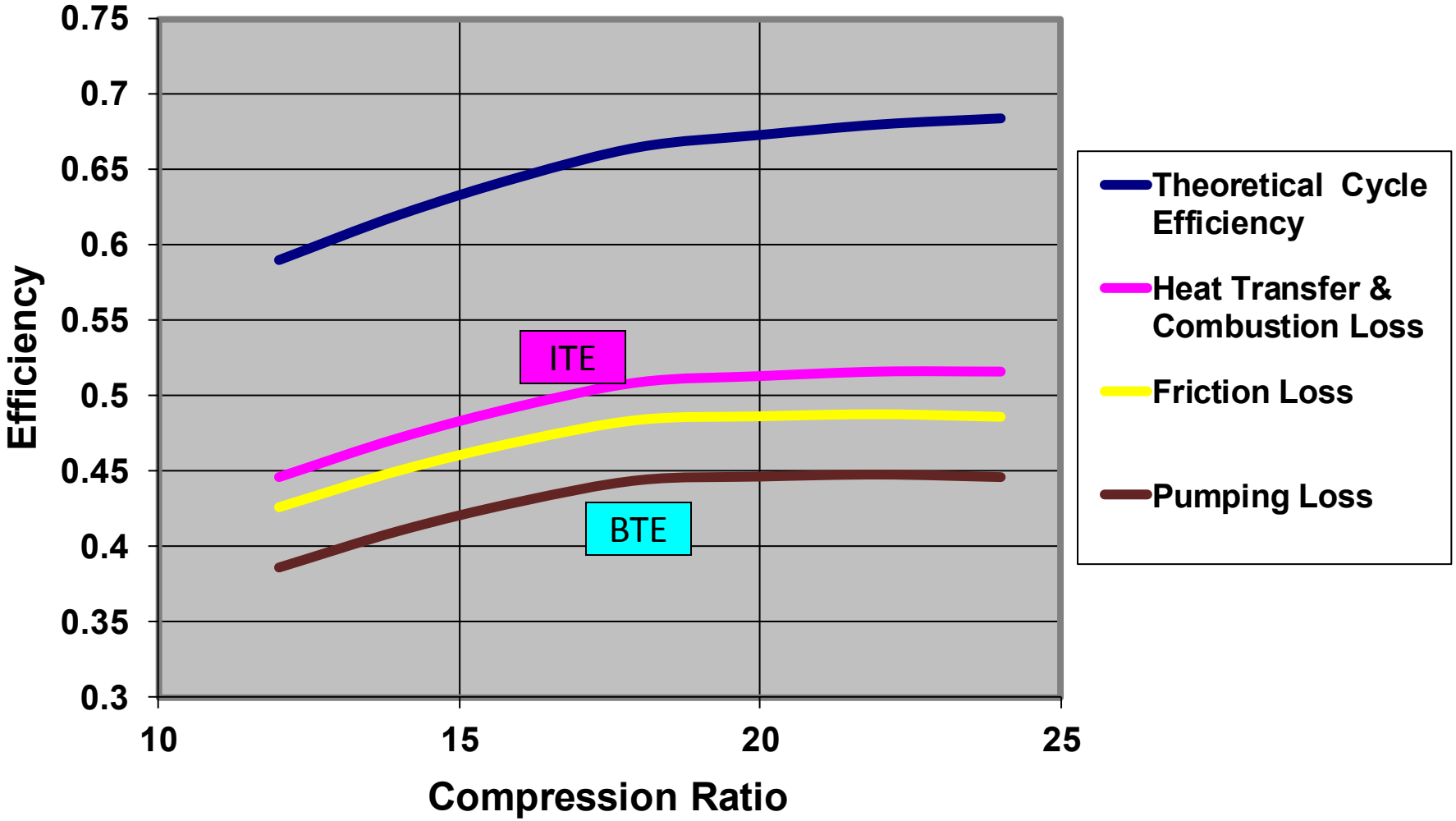
Efficiency goes up with r_c

Efficiency goes up with Gamma

Is it really this simple?

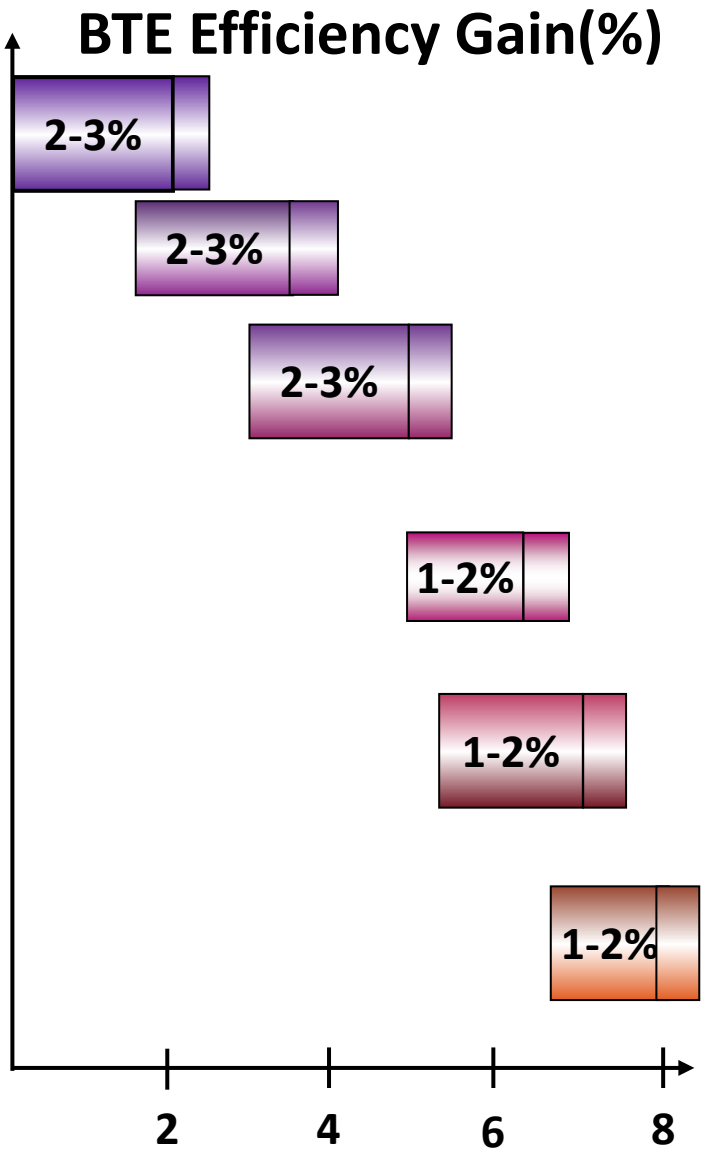
Gamma (Cp/Cv) for dry air is 1.4 at 20 C.
Gamma decreases with increasing temperature.
Gamma decreases for burned gases vs unburned gases. (EGR is negative)

Efficiency vs. Compression Ratio



Path from 43% to 50% Thermal Efficiency?

- Combustion
  - Peak cylinder pressure
  - High efficiency SCR to decouple NOx/efficiency trade-off
- Turbocharger & gas handling efficiency
- Exhaust & EGR Heat Energy Recovery
  - Turbo-compound
  - Rankine cycle
  - Thermo-electric
- Friction, lubricants
  - Efficient accessories
- Managing engine speed & load within optimal efficiency range via powertrain innovation
  - Hybridization in appropriate duty cycles
  - Idle elimination
- Alternative premixed combustion strategies
  - RCCI, PCCI, LTC



Conclusions

- Although electrification options are feasible to displace a majority of fossil fuel in light duty applications, this is not true for long-haul, heavy duty.
- There are no significant alternatives to ICE's for long-haul heavy transport.
- Diesel cycle engines will continue dominate in this market
  - Even natural gas engines will likely be compression ignition for long-haul
  - Other fuels (even typical SI fuels) may be used in low temperature combustion schemes
- Secondary waste heat recovery cycles will see increasing use
- Efficiency will be driven by fuel cost and by regulation
  - NOx battle has been won
  - Efficiency and GHG is the new front