SI Engine Technologies for Improved Fuel Economy

University of Wisconsin Engine Research Center
Engine Research Symposium
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Presented by Eric Curtis
Ford Motor Company

Research & Advanced Engineering

Key Areas Addressed

- Background and Vehicle Perspective
- Engine Efficiency Opportunities
- Government Requirements
- The Marketplace
- Summary

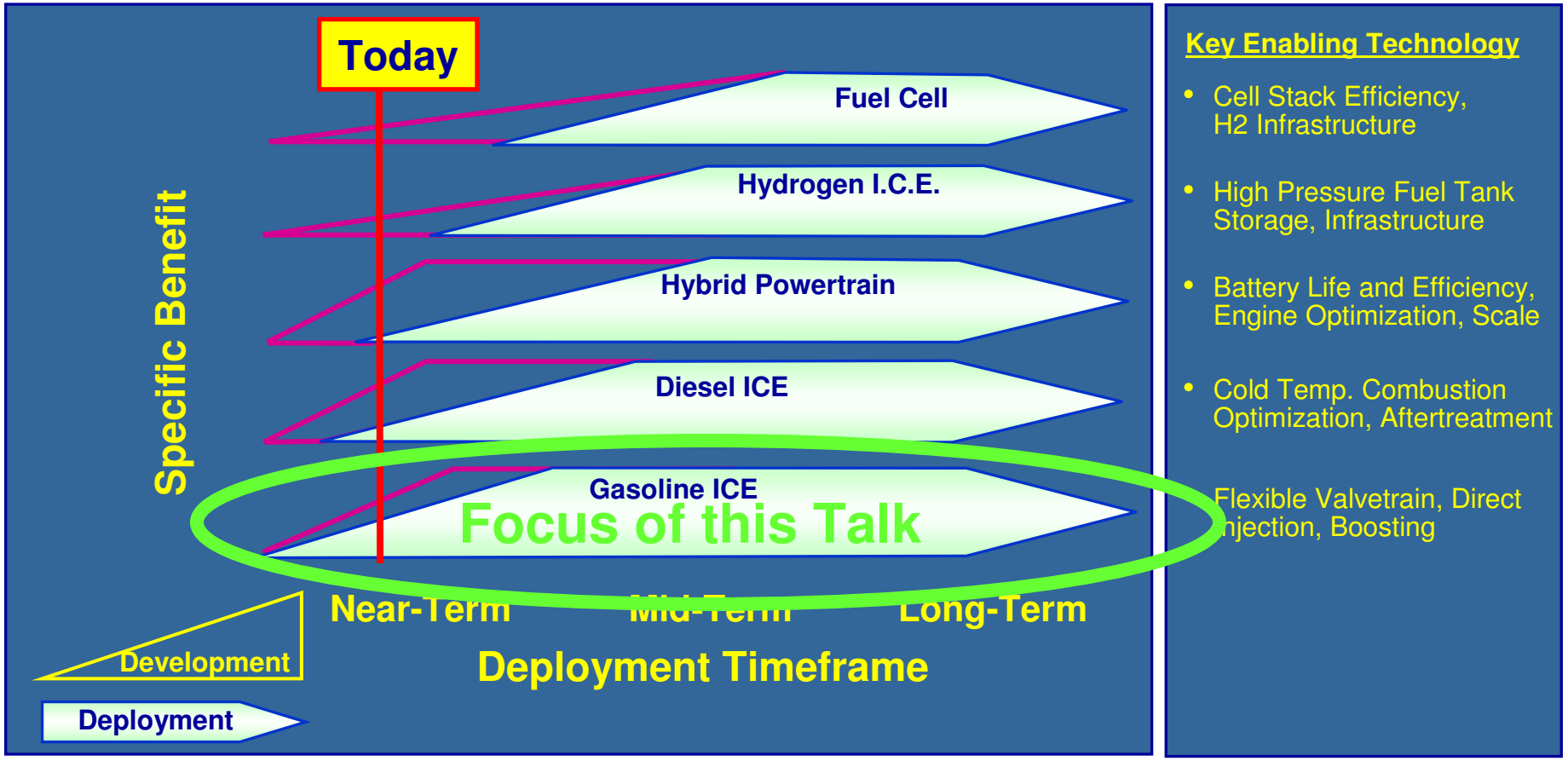
Acknowledgments: Tom Kenney, Patrick Phlips, Brad Boyer, Tom Megli, Tom Leone, Rod Tabaczynski

… and many others!

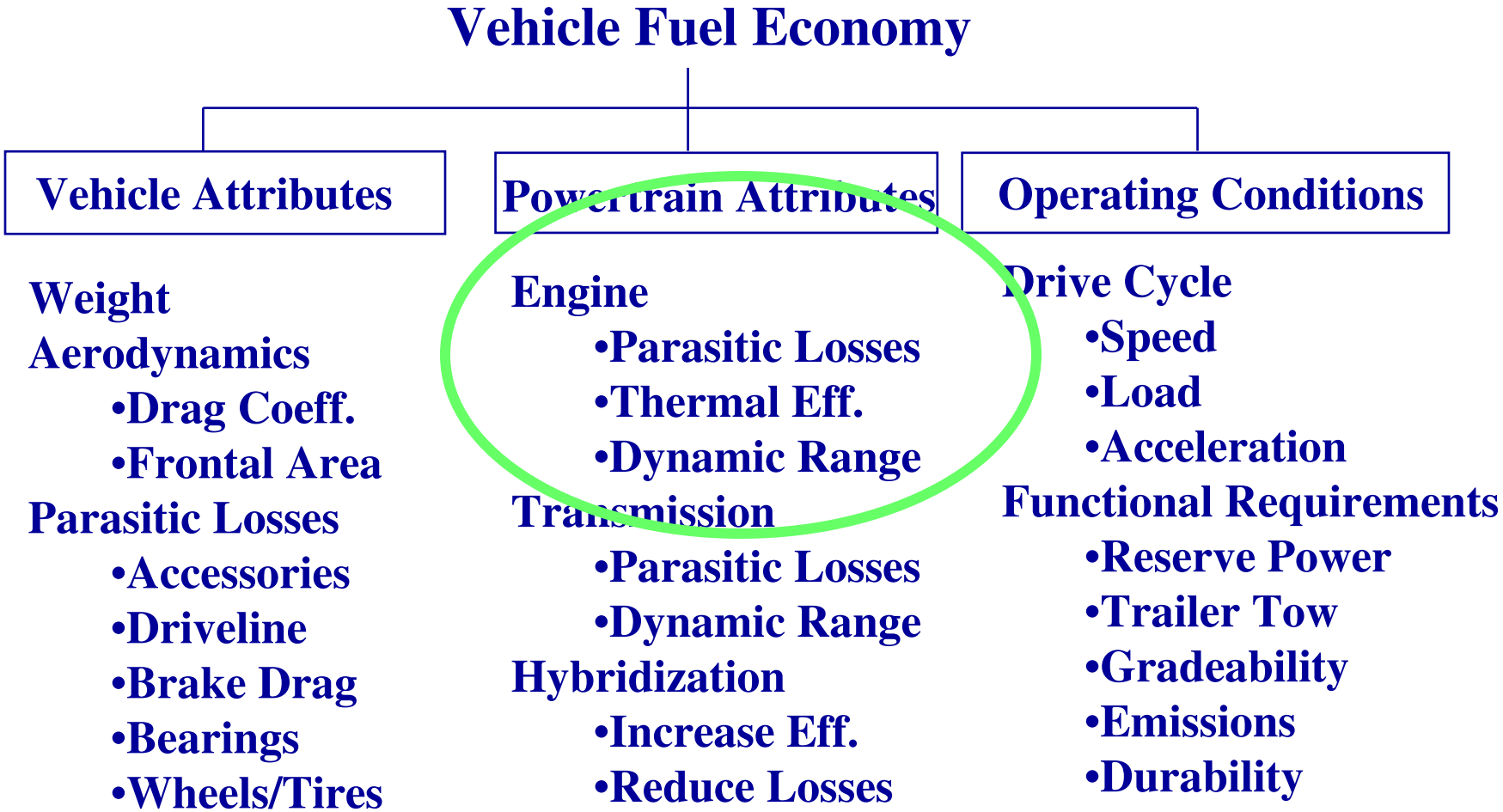
Although conventional SI engine powertrains will dominate the U.S. fleet for the foreseeable future, they will be increasingly replaced by alternatives. As yet, no single global technology solution has emerged.

Challenge:

Proper selection, development, and implementation of eventual "winner(s)".



Factors Affecting Vehicle Fuel Economy

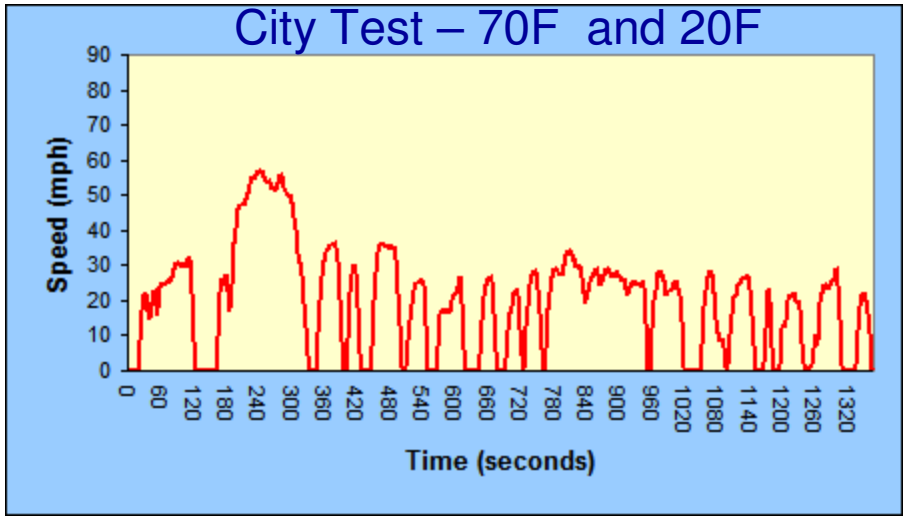


Rod Tabaczynski, March 25, 1999

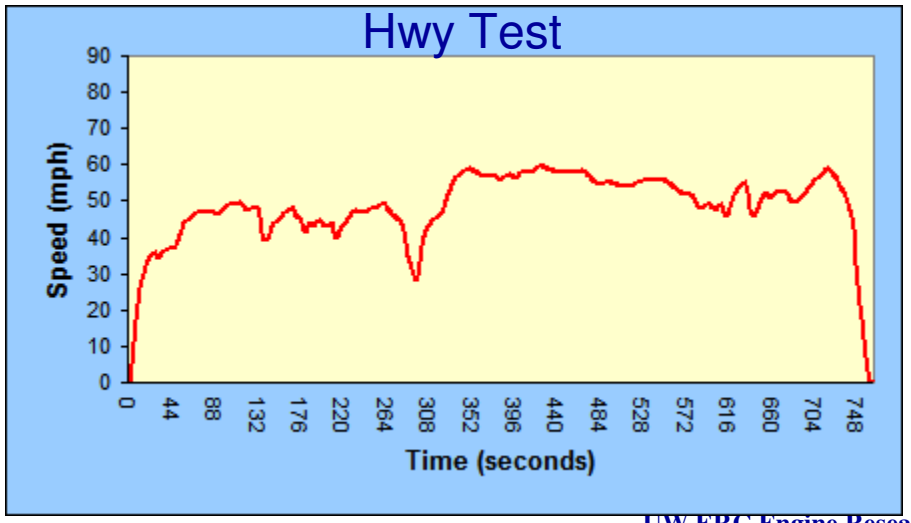
Example Drive Cycles

www.fueleconomy.gov

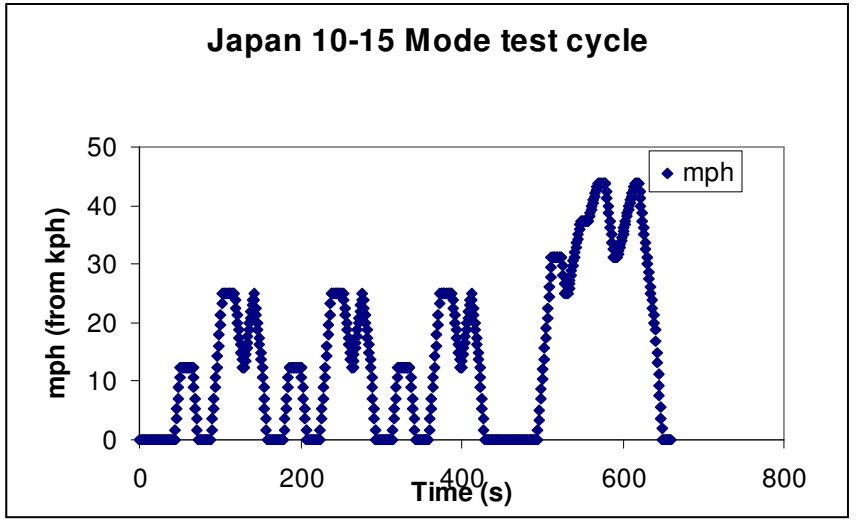
City Test – 70F and 20F

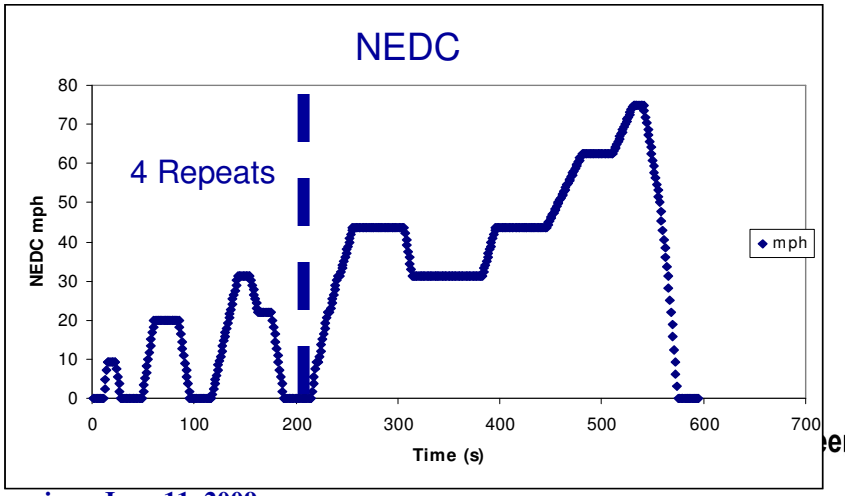


Hwy Test



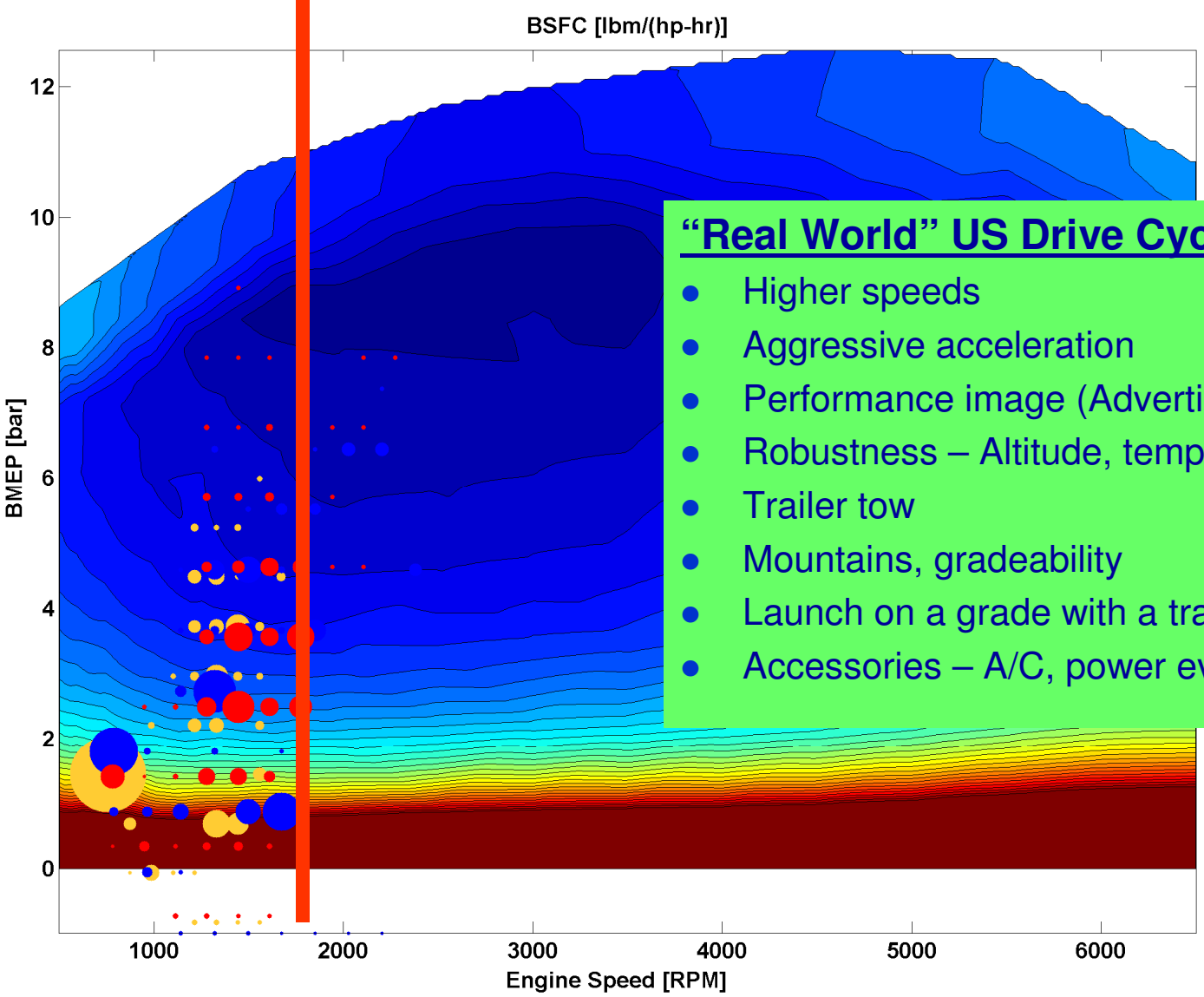
Global Drive Cycle Examples





Generic NA PFI SI Engine Example - Fuel Consumed for Various Drive Cycles

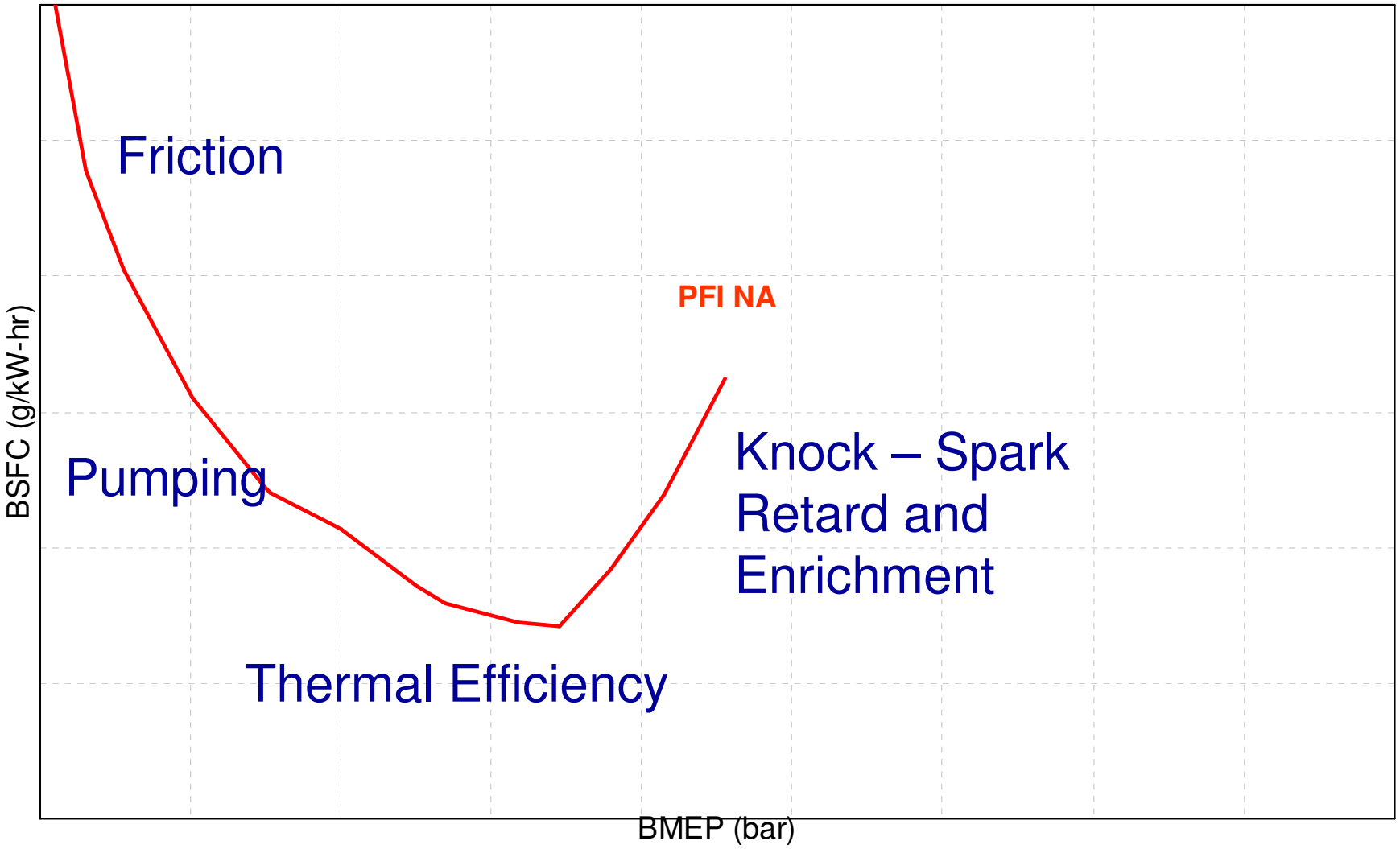
BMEP Sweep



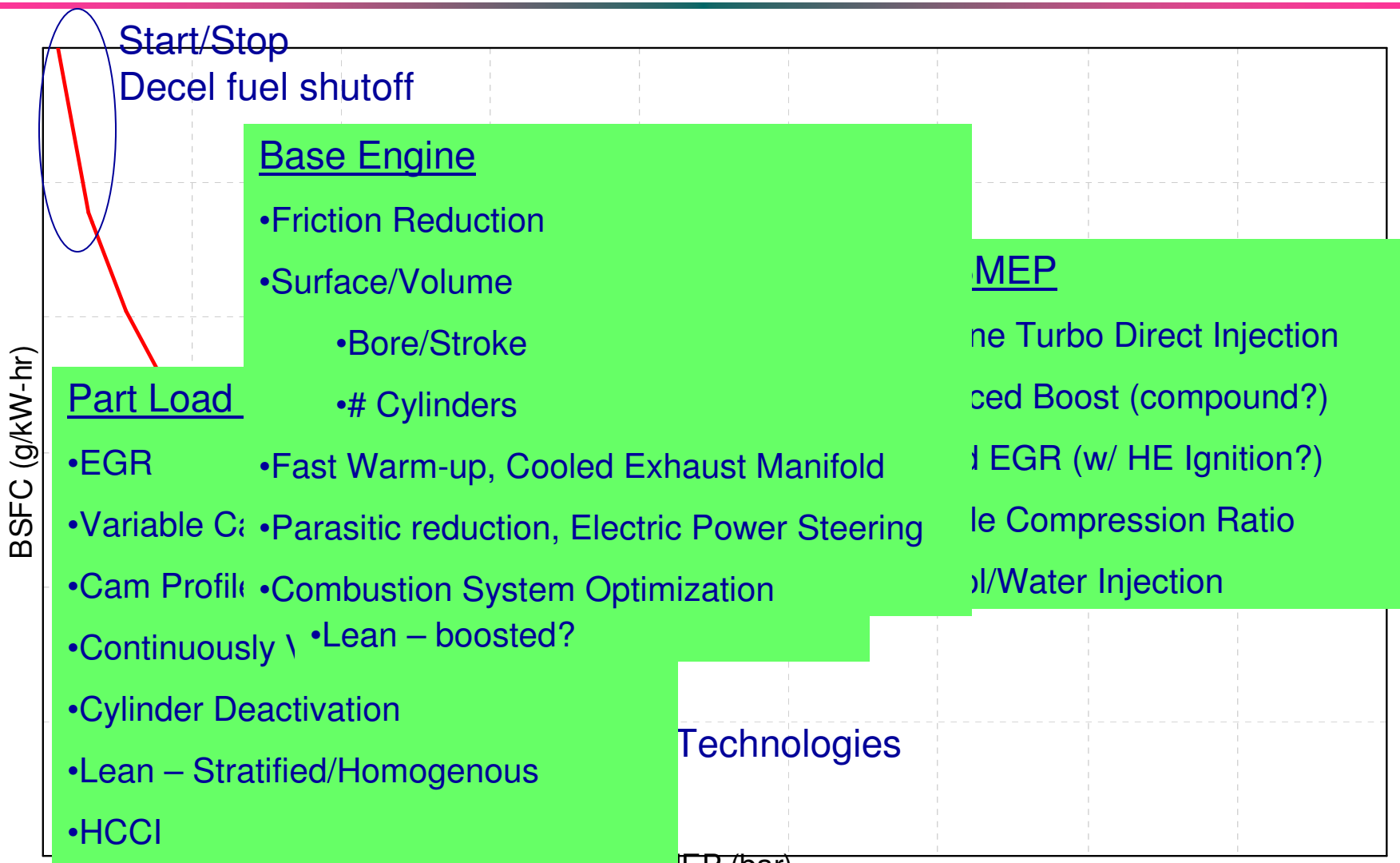
“Real World” US Drive Cycles

- Higher speeds
- Aggressive acceleration
- Performance image (Advertise-able HP)
- Robustness – Altitude, temperature extremes
- Trailer tow
- Mountains, gradeability
- Launch on a grade with a trailer!
- Accessories – A/C, power everything

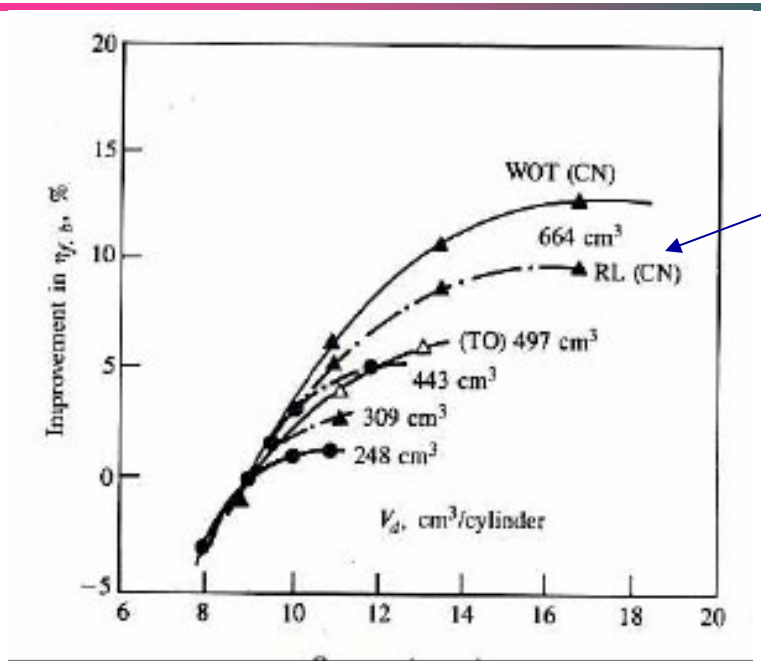
2000 RPM BSFC Opportunities



Example: 2000 RPM BSFC Opportunities



Effect of CR and Cylinder Displacement on Thermal Efficiency



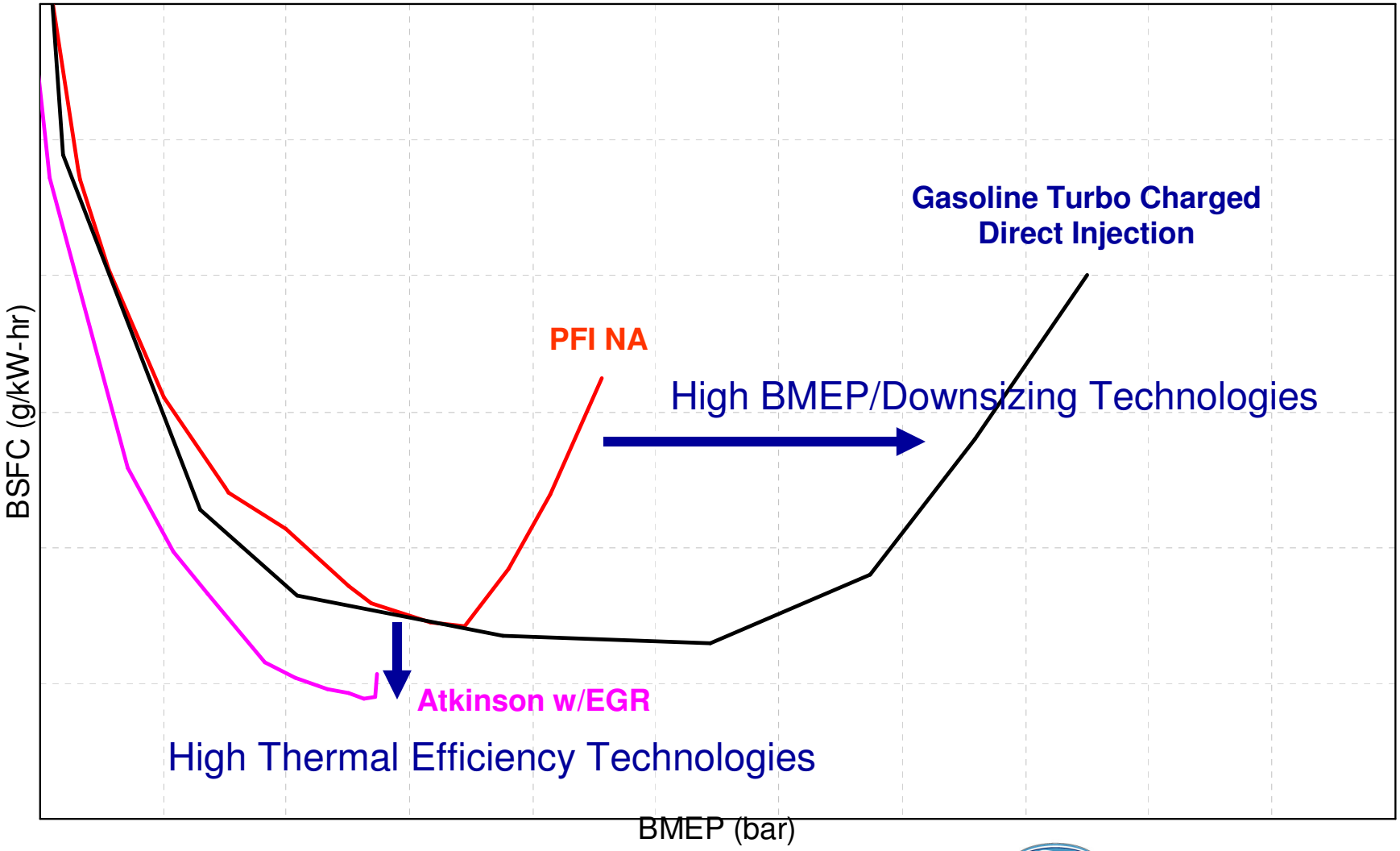
Best CR changes with cylinder displacement due to: S/V Heat Transfer Effects, Flame Quenching and Crevice Effects.

Best CR limit may be ~13-14:1?

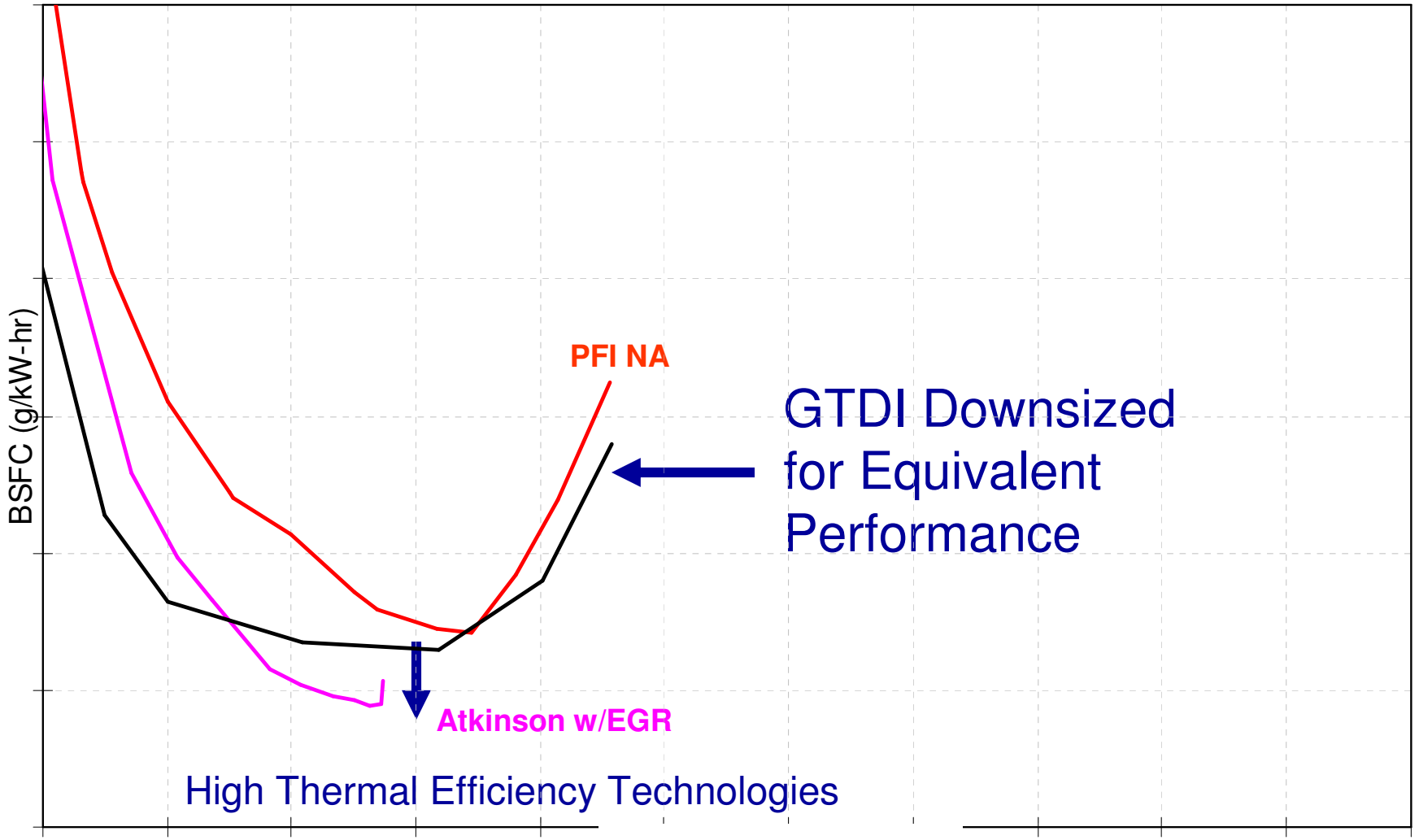
FIGURE 15-14
Relative brake fuel conversion efficiency improvement with increasing compression ratio of spark-ignition engines of different displaced volume per cylinder at part throttle (except top curve at WOT).[19] RL road load. CN,[17] TO.[10]

From Heywood, Page 843: Caris and Nelson, 1959, Thring and Overington, SAE-820166, Muranaka, S., Takagi, Y., and Ishida, T., SAE 870548.

Engine Technology Examples



Engine Technology Examples



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Effect of Lean Operation

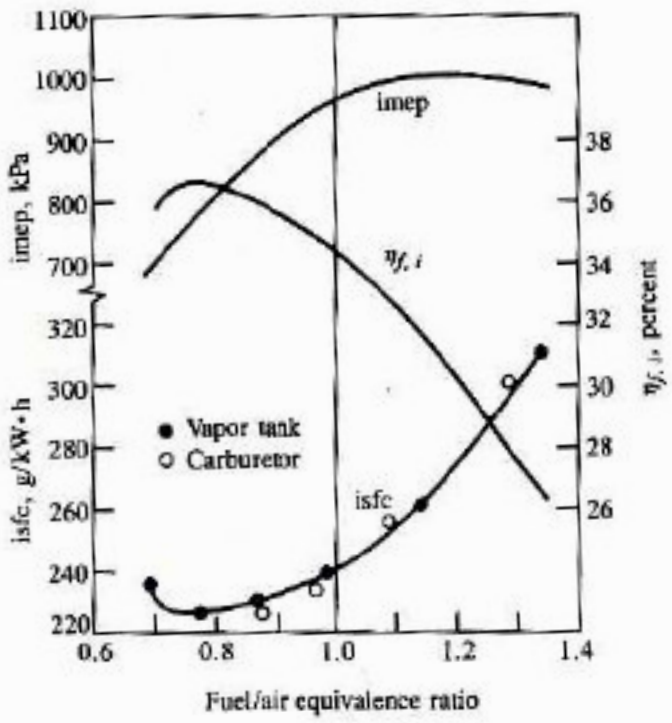


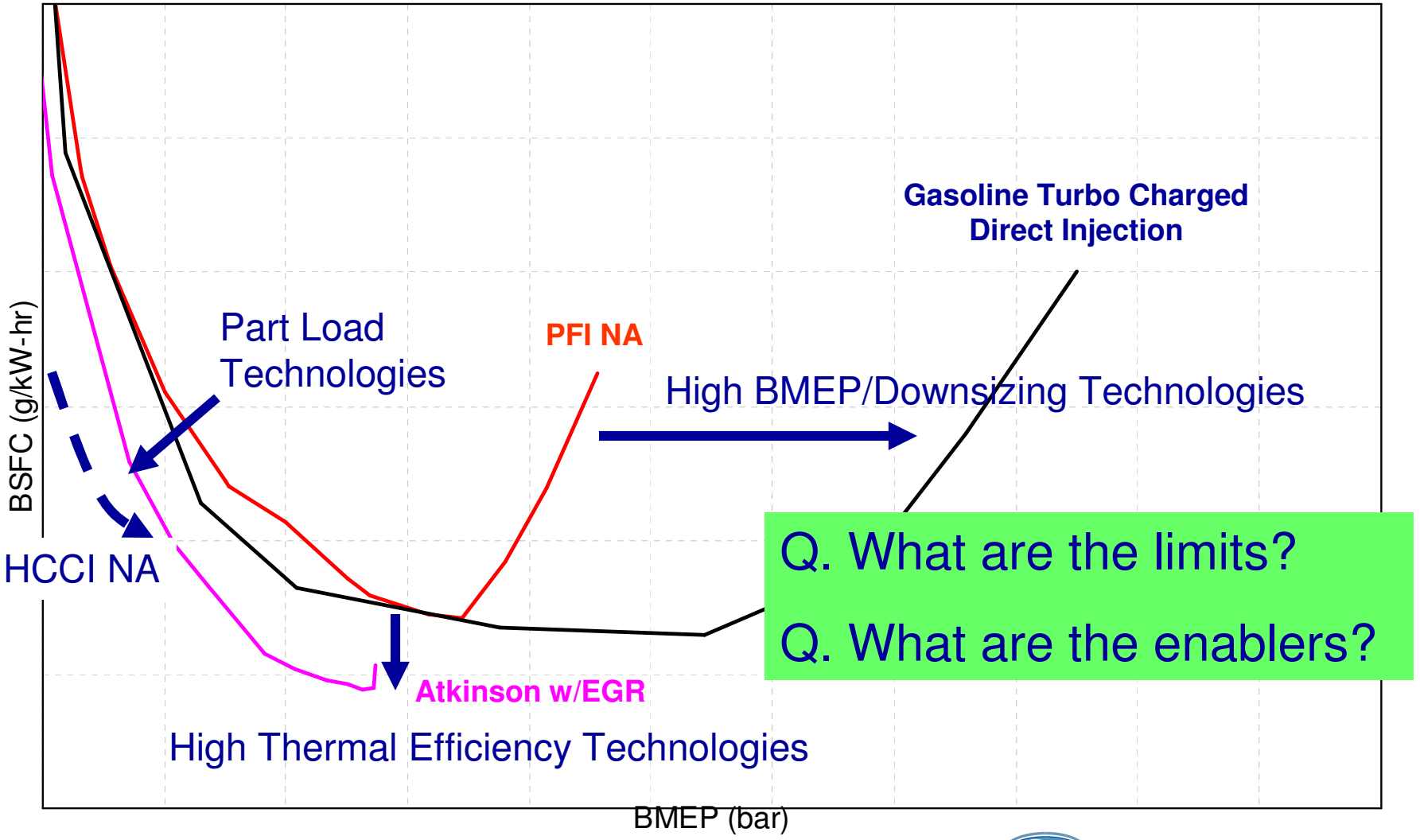
FIGURE 15-4
Effect of the fuel/air equivalence ratio variations on indicated mean effective pressure, specific fuel consumption, and fuel conversion efficiency of six-cylinder spark-ignition engine at wide-open throttle and 1200 rev/min. Data for standard carbureted engine, and engine equipped with vapor tank which extends the lean operating limit, are shown.[9]

Running 20% Homogenous Lean gives ~6% BSFC improvement. Stratified and HCCI benefits may be even more.

Lean aftertreatment requirements may be very challenging (PZEV)

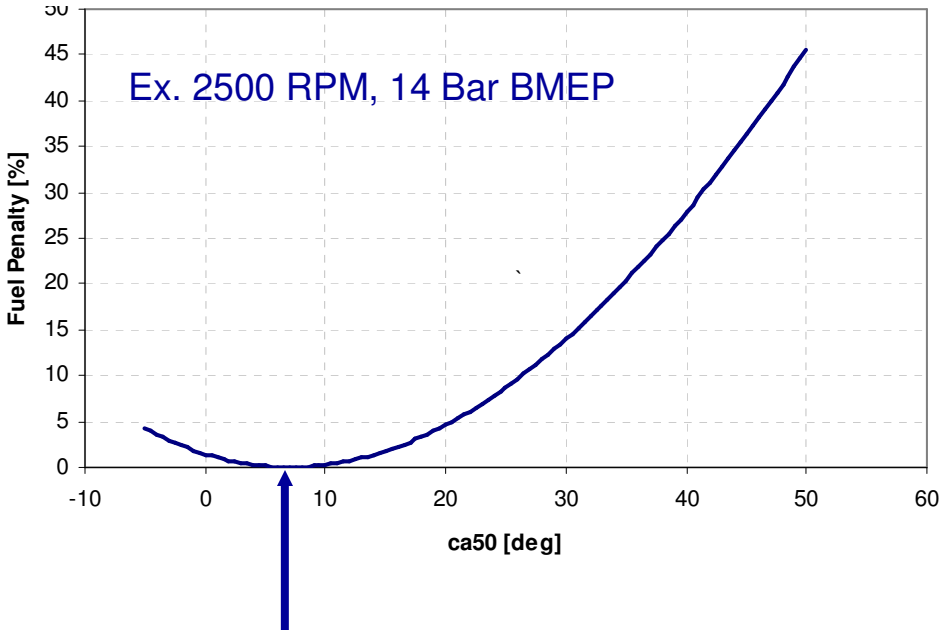
From Heywood, Page 831: Robison and Brehob, "The Influence of Improved Mixture Quality on Engine Exhaust Emissions and Performance", J. Air Pollution Control Ass., vol. 17 no.7, pp. 446-453.

Engine Technology Examples



Effect of Knock and Combustion Phasing

- At higher loads, knock forces spark retard which reduces thermal efficiency and raises exhaust gas temperature.
- At high speeds and loads, the exhaust gas temperature may rise above the thermal limits of the turbo or catalyst requiring enrichment.
- Downsized engines running at high loads may require reduction in CR, reducing efficiency.



MBT CA 50 ~ 7-9 CA

Engine Efficiency Opportunities Summary

Base Engine

- Friction Reduction
- S/V (B/S, # Cylinders)
- Fast Warm-up, IEM
- Parasitic reduction, Electric Access.
- Combustion System Optimization

High BMEP

- GTDI
- Advanced Boost (compound?)
- Cooled EGR (w/HE Ignition?)
- Variable Compression Ratio
- Ethanol/Water Injection

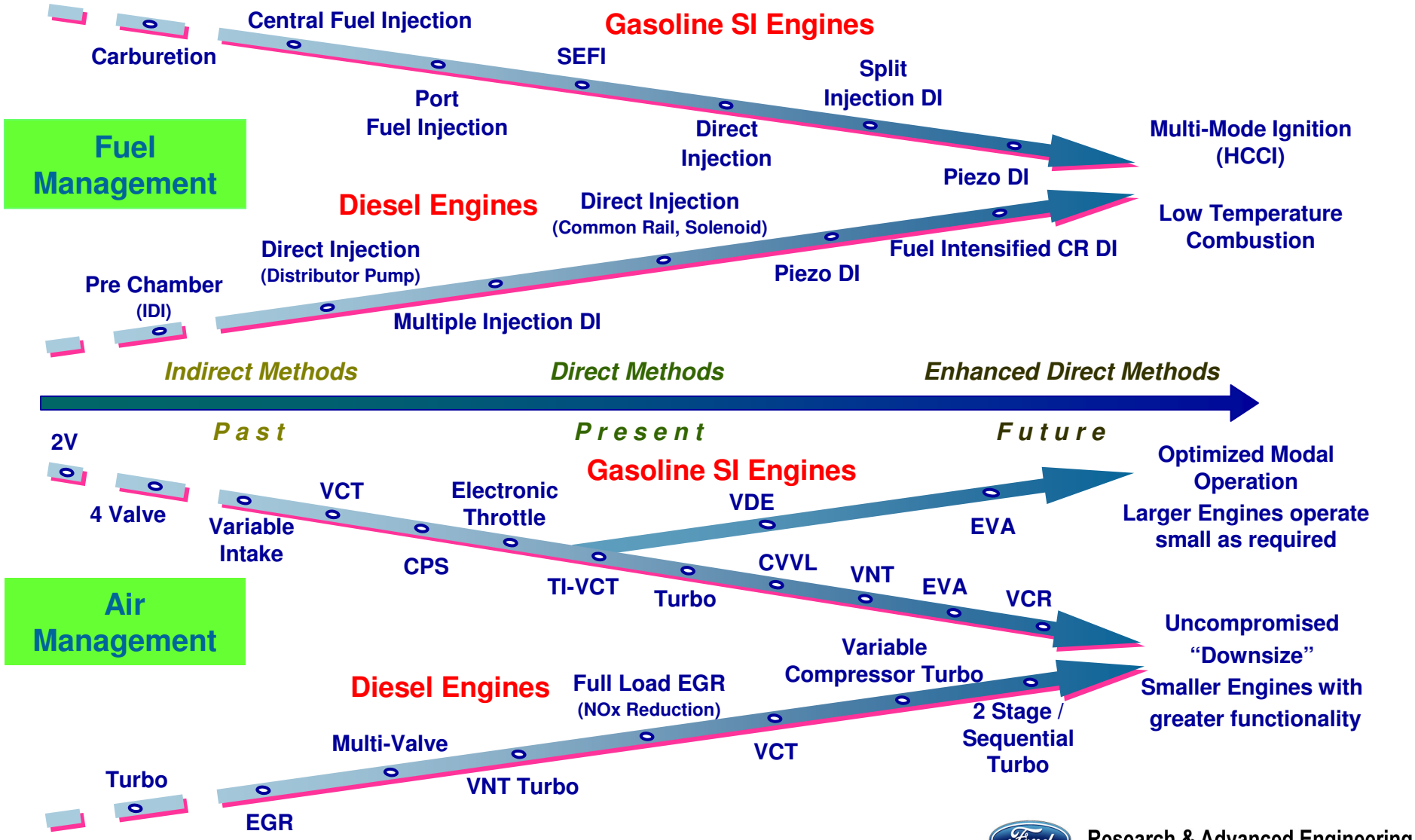
Max Thermal Efficiency

- CR/ER Optimization – Atkinson
- EGR, cooled EGR
- Variable Compression Ratio
- Lean – boosted?

Part Load Technologies

- Stop/Start
- Decel Fuel Shutoff
- EGR
- VCT : CVVL: EVA
- Cylinder Deactivation
- Lean – Stratified/Homogenous
- HCCI

Trends converge for gasoline and diesel engine technologies with respect to:
- Fuel Management - increased flexibility in control of fuel delivery
- Air Management - higher volumetric efficiency, flexible cylinder operation



Powertrain Attributes - Engine

Engine Attributes

Parasitic Losses

Mechanical Friction
- Rubbing Losses
- Accessories

Pumping Losses
- Throttling

Thermal Efficiency

- Compression Ratio
- Equivalence Ratio
- Load Factor
- Displacement per Cylinder
- Dilution (EGR)
- Combustion Efficiency
- Combustion Stability

Dynamic Range

Engine Speed Range

4 – Valve
VCT

Load Range

- Turbocharging
- Supercharging

Rod Tabaczynski, March 25, 1999

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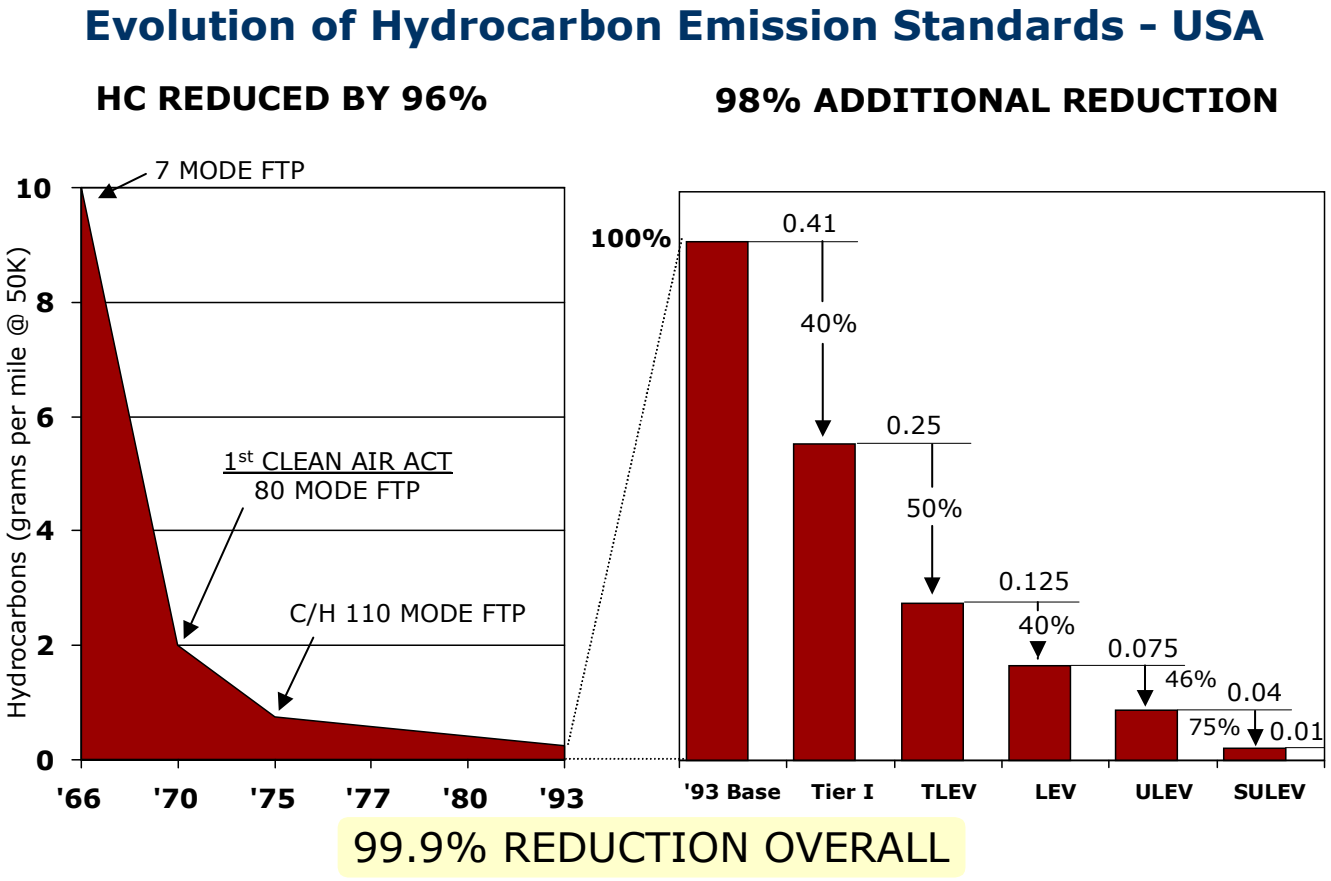
Emissions Standards are really tough!



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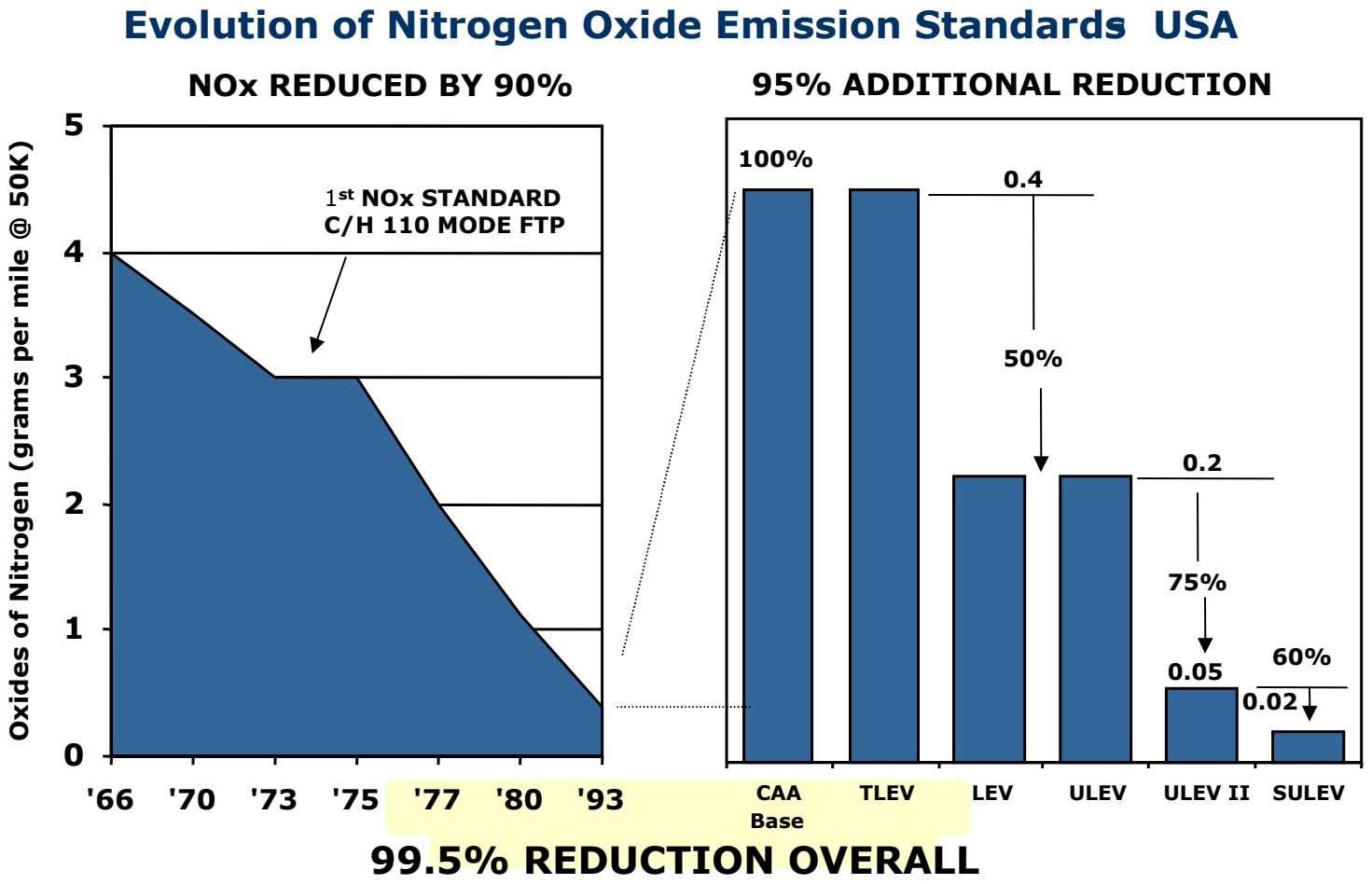
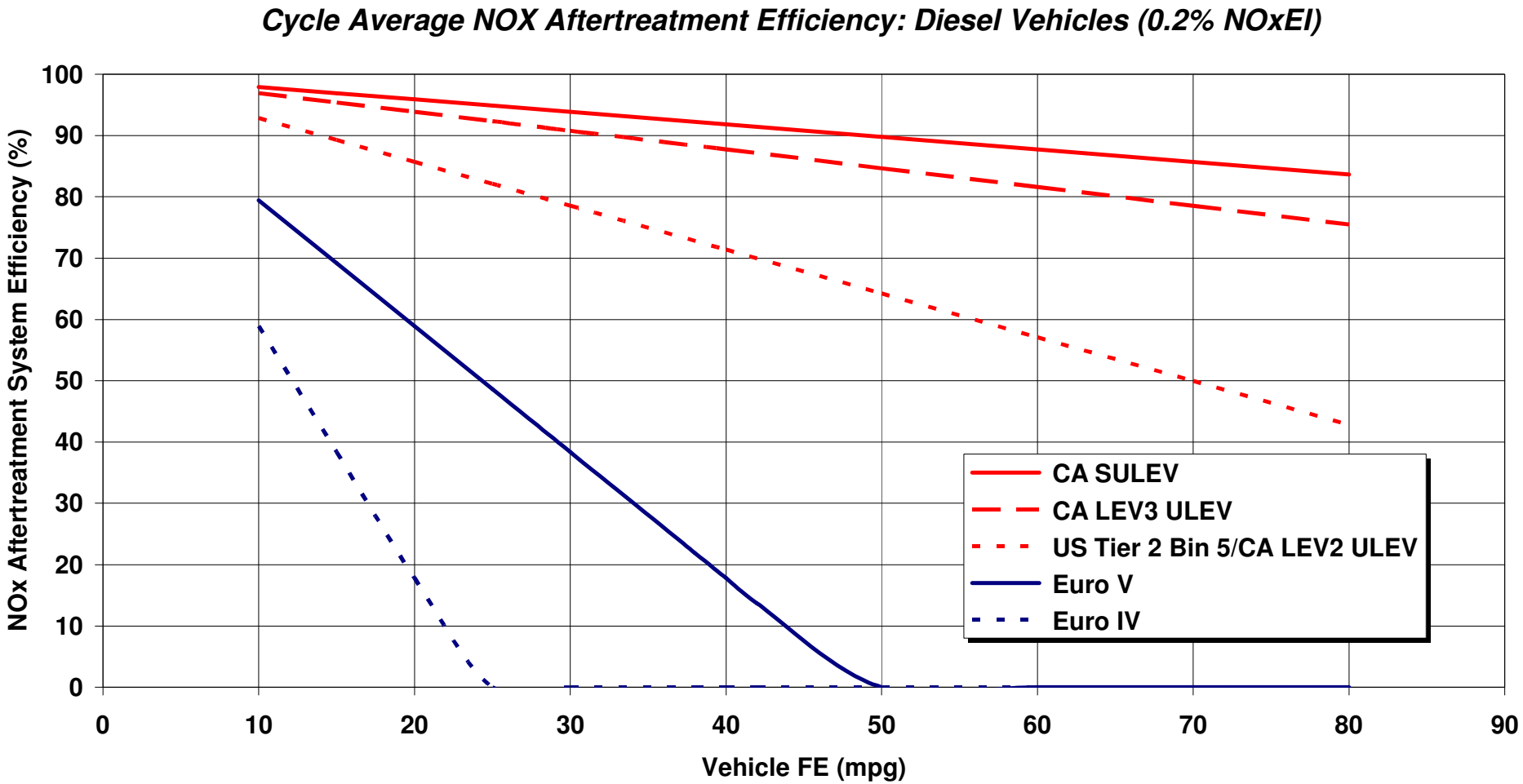


Example of Lean Aftertreatment requirements for Diesel. CA standards can require lean NOx conversion efficiencies of >95%



European diesel tailpipe NOx standards are less stringent than those in the US

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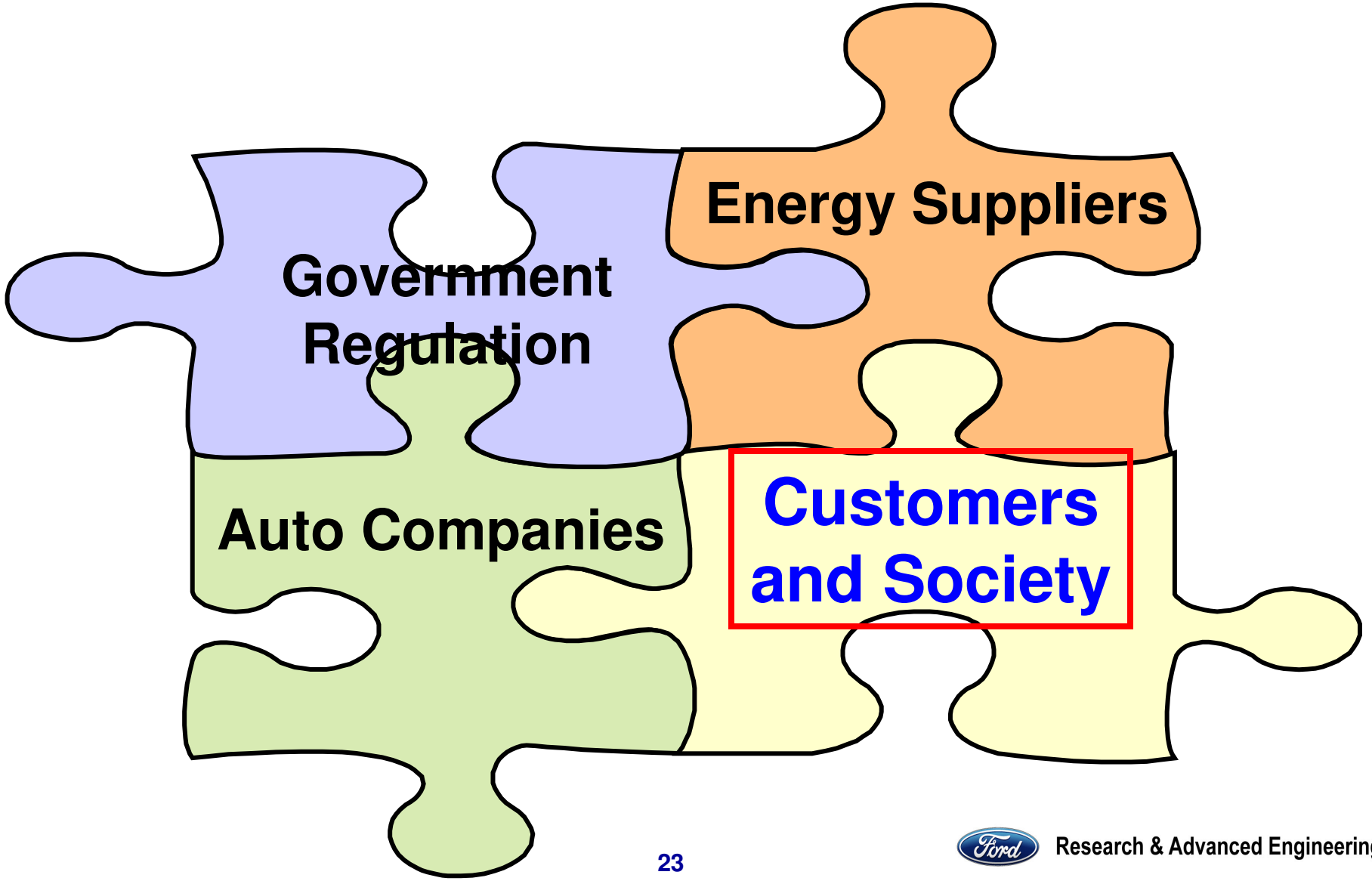
Customers must recognize and realize the benefits for a fuel or technology to succeed in the market. All must win!!!

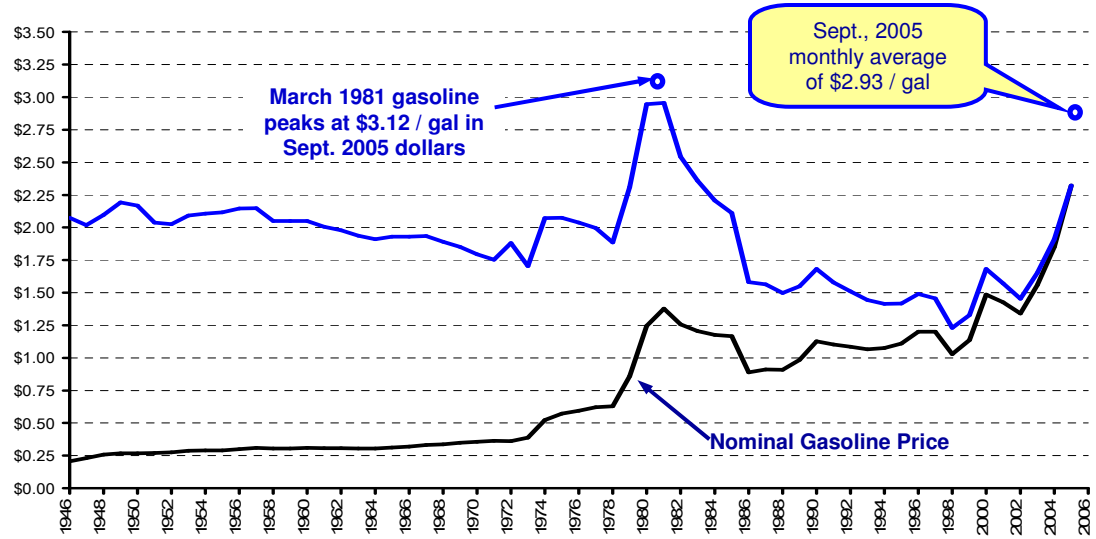


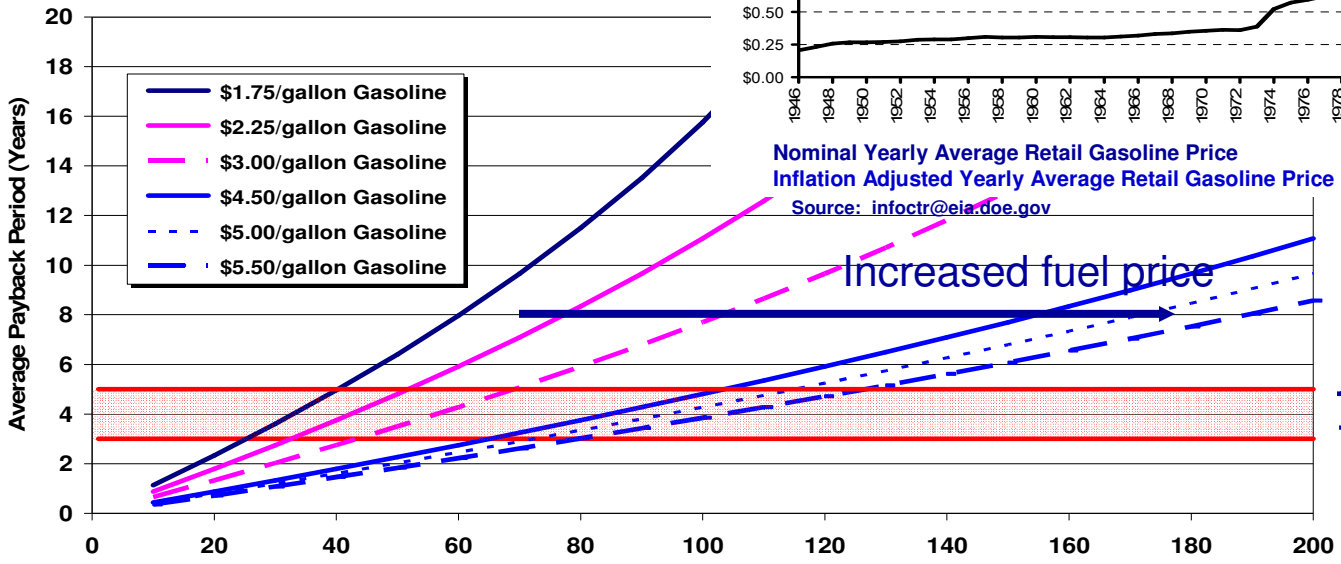
Customer Expectations

- Performance and fun to drive
- Drive-ability, launch feel and transient response
- Robustness – must work reliably everywhere on Earth
- NVH (challenge with fewer cylinders)
- Image and Style (Green, Sporty, etc.)
- Convenience – fuel availability, range
  - multiple fuel/after-treatment tanks?
- Maintenance requirements – frequency and cost
- Capability – trailer tow, gradeability etc.
- Value – life cycle costs, (initial, operating, resale)

Customer payback period for technologies that improve FE depends on fuel price; as fuel prices increase, payback periods decrease.

Fuel Prices fundamentally impact the value and payback period of new fuel saving technologies. Customers demand value.





Higher Fuel Prices justify higher cost technologies

High Value → Lower Value Technologies

Customers want it all

- Blog: USA Today 05/17/09 by Chris Woodyard
- **Only one out of four people are willing to pay more to buy a gas-electric hybrid vehicle** …
- Yet Americans are overwhelmingly supportive of the notion of hybrids, ….
- "The survey makes one message abundantly clear: … consumers need costs to come down for the hybrid industry to thrive," said Kim Metcalf-Kupres, a Johnson Controls vice president in a statement.

The U.S. passenger car and light duty truck fleet turns over in ~15 years. At present, gasoline engine powertrains dominate. U.S. fleet size is growing at 1% per year

US Car & LDT Sales	**~12-17 M**
Hybrid	**1.3%**
Diesel	**3%**
H_2 ICE/FCV/FCEV	**nil**
US Car & LDT Fleet	**~220 M**
Hybrid	**<0.2%**
Diesel	**2%**
H_2 ICE/FCV/FCEV	**nil**
Customers	
Have Paid for	**Quality, Function, Performance**
Have Not Paid for	**Low Emissions, FE**

With a US Light Duty Fleet of ~220 M vehicles, the time scale for significant market penetration of small volume technologies is rather long.

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Conclusions/Challenges

- Improved Fuel Economy requires a total vehicle level system optimization, however the engine is a critical part of that system
- There are several competing/complimentary paths for improved engine efficiency (High BMEP/downsizing, High Thermal Efficiency, Part Load Improvements)
- Success in the marketplace depends on satisfying customer expectations and needs with affordable products
- Customer and regulatory demands for more fuel efficient vehicles are growing rapidly
- No single technical prescription for improving FE on all vehicles in all markets or market segments has emerged
- Development and deployment of advanced vehicle, transmission and engine technologies continues at a rapid pace