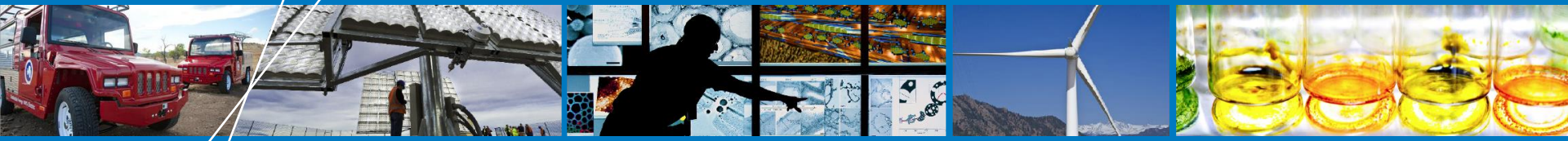
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Regulatory and Commercial Barriers to Introduction of Renewable Super Premium



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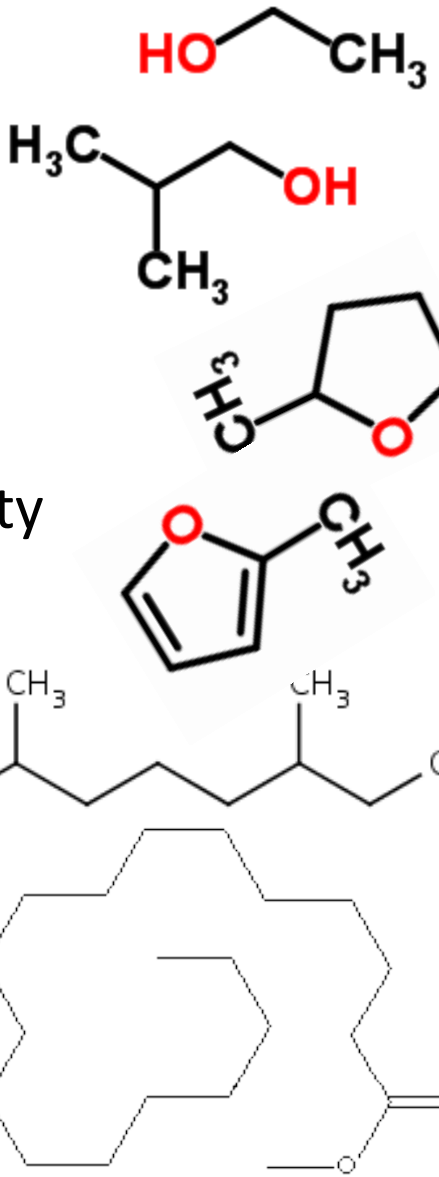
Introducing New Fuels

- **Many steps and years to introduce a new fuel**
- **Impact on:**
  - Vehicle performance and durability
  - Emissions and emission control system durability
  - Toxic emissions and health effects
  - Infrastructure compatibility
  - Fuel quality standards
  - Fire codes and safety regulations
  - Consumer protection laws
  - Federal, state, and local regulations/laws



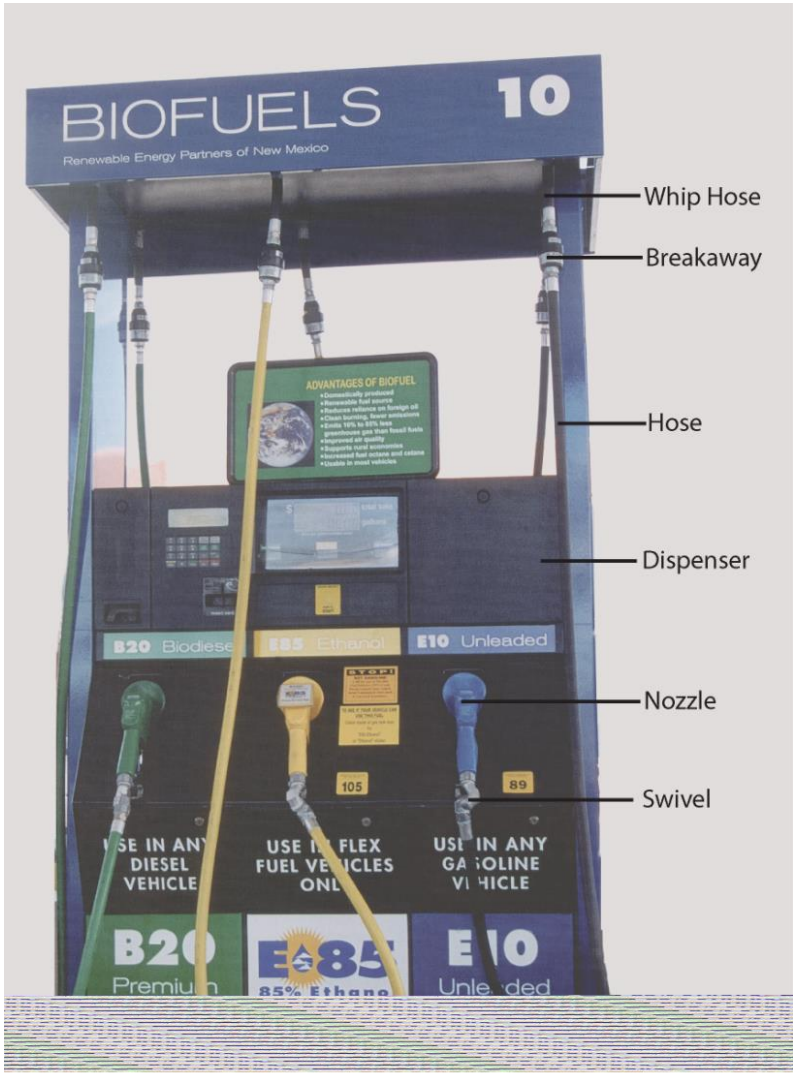
Infrastructure-Underground Storage Equipment

- EPA's Office of Underground Storage Tanks (OUST)
  - 40 CFR Part 280 requires UST must be compatible with fuel stored

- OUST Issued "Guidance - Compatibility Of UST Systems With Biofuel Blends" in July 2011
- Existing equipment considered compliant with E10 and B20
- For higher blend levels, two paths to compliance:
  - Components are listed by an independent testing laboratory for use with the fuel stored
  - Components approved by the manufacturer to be compatible with the fuel stored
  - Steel tanks generally compatible with any ethanol blend
  - Fiberglass tanks generally compatible after 1990

Infrastructure-Other Equipment

- OSHA requires third-party listing of dispenser, nozzle, and breakaway for specific fuel
- Local fire marshal may also require third party listing
- UL lists above-ground equipment for various fuels
- *All necessary equipment including shear valves, hanging hardware, and dispensers are available with UL approval up to E85*



Fuel Quality Standards

- **Consensus commercial standards developed by ASTM members**
  - Anyone can join ASTM
  - But typically fuel producers and distributors, engine/car makers, state fuel regulators, other interested parties
- **New standard potentially required for renewable super premium**
- **Standard will focus on properties required to enable much more efficient engines**
  - But also include a range of other performance requirements, similar to D4814 and D5798

Approaches to Increasing Engine Efficiency

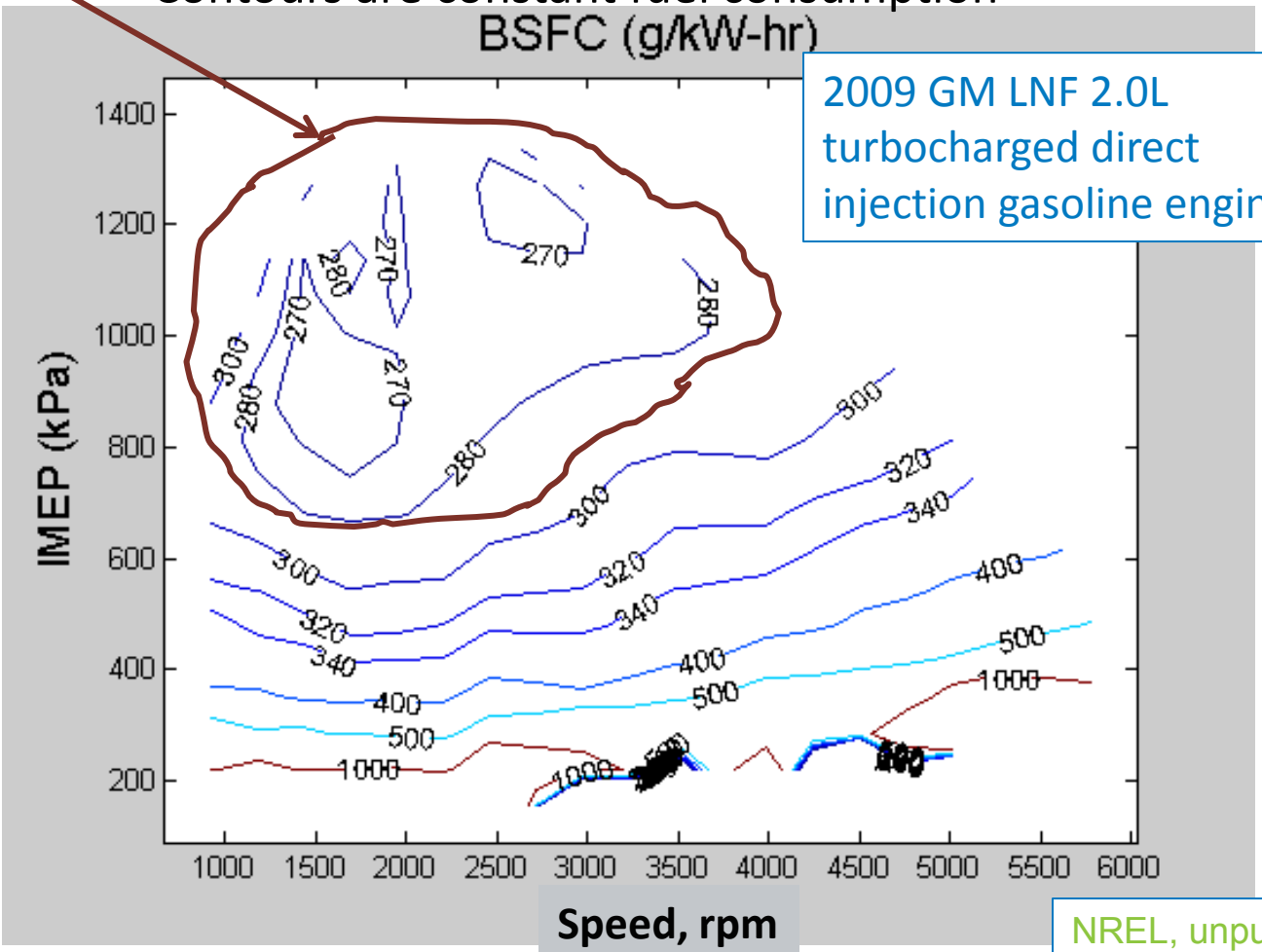
- **Turbocharging**
  - Recovering energy from the engine exhaust
  - Required for engine downsizing
- **Engine down-sizing and down-speeding**
  - Smaller engines operating at low-speed and higher load are more efficient
  - Optimized with 6 to 9 speed transmission
- **Increased compression ratio**
  - Greater thermodynamic efficiency
- **Direct injection**
  - Fuel evaporates in the combustion cylinder, cooling the air-fuel mixture
  - Also required for engine downsizing

Engine Downsizing/Down-Speeding Fuel Demand

Most knock limited region – and highest fuel economy

→ Requires higher fuel knock resistance

Contours are constant fuel consumption

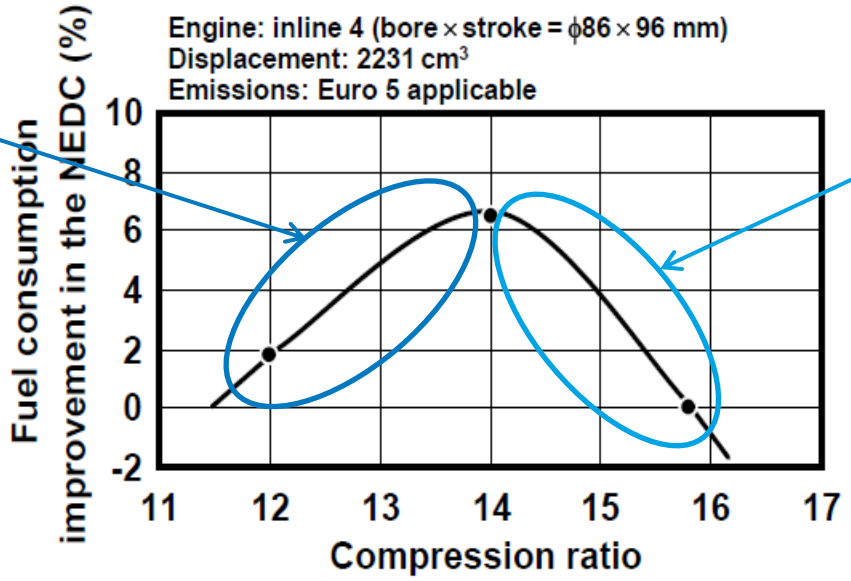


2009 GM LNF 2.0L turbocharged direct injection gasoline engine

NREL, unpublished data

Effect of Increasing Compression Ratio

Increasing efficiency as CR increases



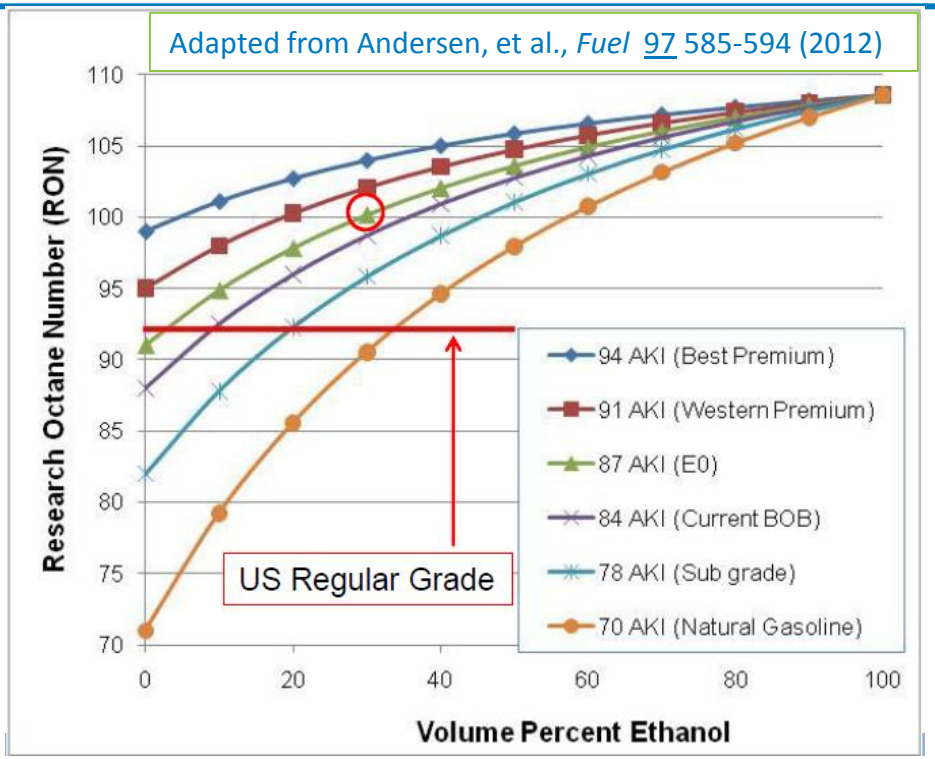
Efficiency loss caused by increased piston ring friction

- Higher compression ratio yields higher temperature and pressure; and hence higher efficiency
- Requires higher fuel knock resistance
- An optimal CR exists (typically in the teens) and depends on other engine design features (primarily piston bore size)
- Current engine CR about 10 or lower

Toyota, Aachen Colloquium October 2010

Octane Number and Engine Knock

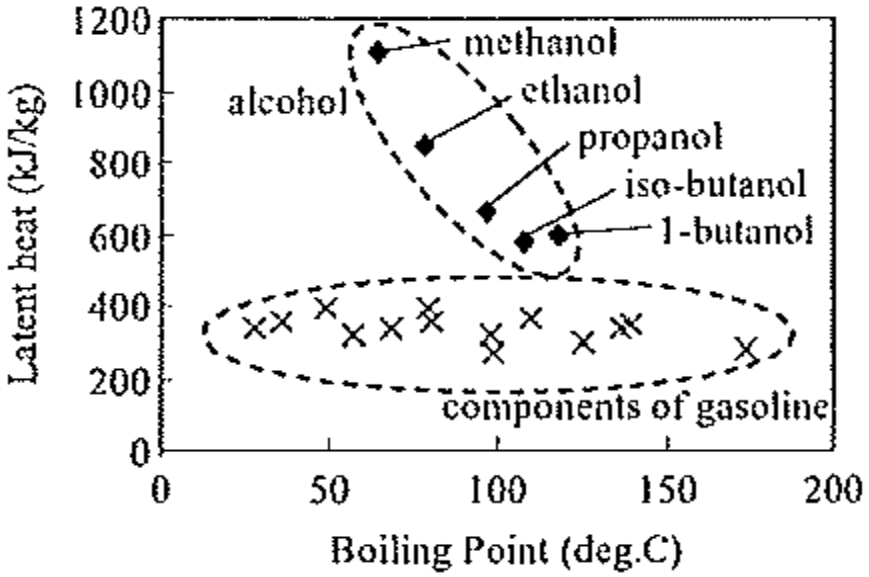
- ON is a measure of resistance to autoignition caused by high temperature and pressure
- Autoignition is knock and can damage the engine
- Higher ON is required for higher CR, turbocharged engines
- Research Octane (RON) – cool and slow
  - Best predictor for small modern engines
- Motor Octane (MON) – hot and fast



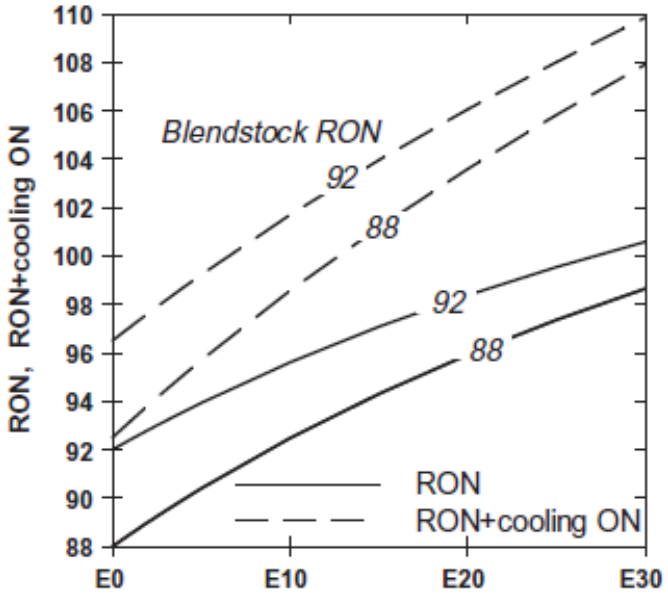
	RON	MON	AKI
Typical US Regular	92	83	87.5
Ethanol	109	90	99.5
Isobutanol	105	90	97.5
Iso-octane	100	100	100
n-Pentane	62	62	62
Toluene	118	104	111

Heat of Vaporization Effect

- For direct injection engines fuel evaporation occurs in the cylinder – cooling the charge and reducing knock tendency
- Alcohols have significantly higher heat of vaporization
- Not captured by ON measurements



Nakata, et al. *Int. J. Engine Res.* 12 274-281 (2011)



Andersen, et al., *Fuel* 97 585-594 (2012)

Summary Comment

- ***Infrastructure***
  - *Dispensers compatible with higher level ethanol blends are available, but not widely deployed*
  - *Most storage tanks are compatible with high level ethanol blends (especially steel), but not all*
- ***Quality standard***
  - *Existing E51-83 standard (ASTM D5798) does not capture fuel properties that enable highly efficient engines*
  - *A new standard may need to be developed that includes both the octane number and heat of vaporization effects on knock resistance – along with other fuel quality parameters*

Acknowledgments

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Thank You!

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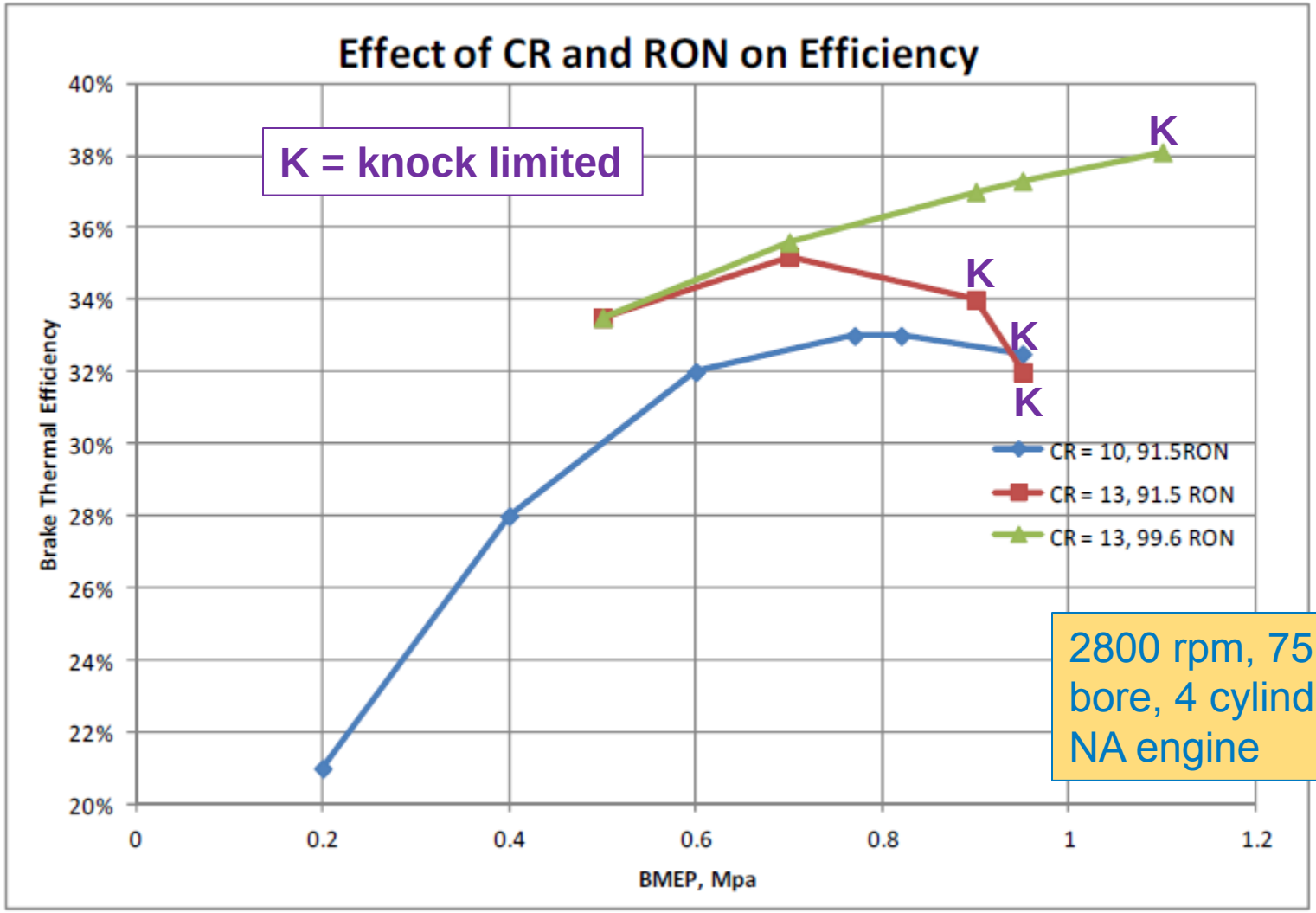
Tank Compatibility

- **Steel Tank Institute has letters from 24 steel tank manufacturers stating compatibility with all ethanol (up to E100) and biodiesel blend (up to B100)**
- **Fiberglass Tank Compatibility:**
  - Owens Corning—single wall up to E10; double wall E10 (1965-7/1/1990) and E100 (7/2/1990-12/1994); no statement on biodiesel
  - Containment Solutions—all tanks all blends E0-E100; B0-B100
  - Xerxes—Tanks prior to 1981 not compatible with any blend; single wall E10 (2/81-7/2005) E100 (7/2005-present); double wall E10 (prior-4/1990) E100 (4/1990-present); all tanks all years for B0-B100
- **Statements of compatibility from associated equipment manufacturers: Ameron, Bravo, Brugg Pipesystems, Morrison Bros., National Environmental Fiberglass, NOV Fiber Glass Systems, Nupi Americas, Omegaflex, Plasteel, Vaporless Manufacturing, and Western Fiberglass**

- **Steel Tank Institute Letters Stating Compatibility: http://www.steeltank.com/Publications/E85BioDieselandAlternativeFuels/ManufacturerStatementsofCompatibility/tabid/468/Default.aspx**

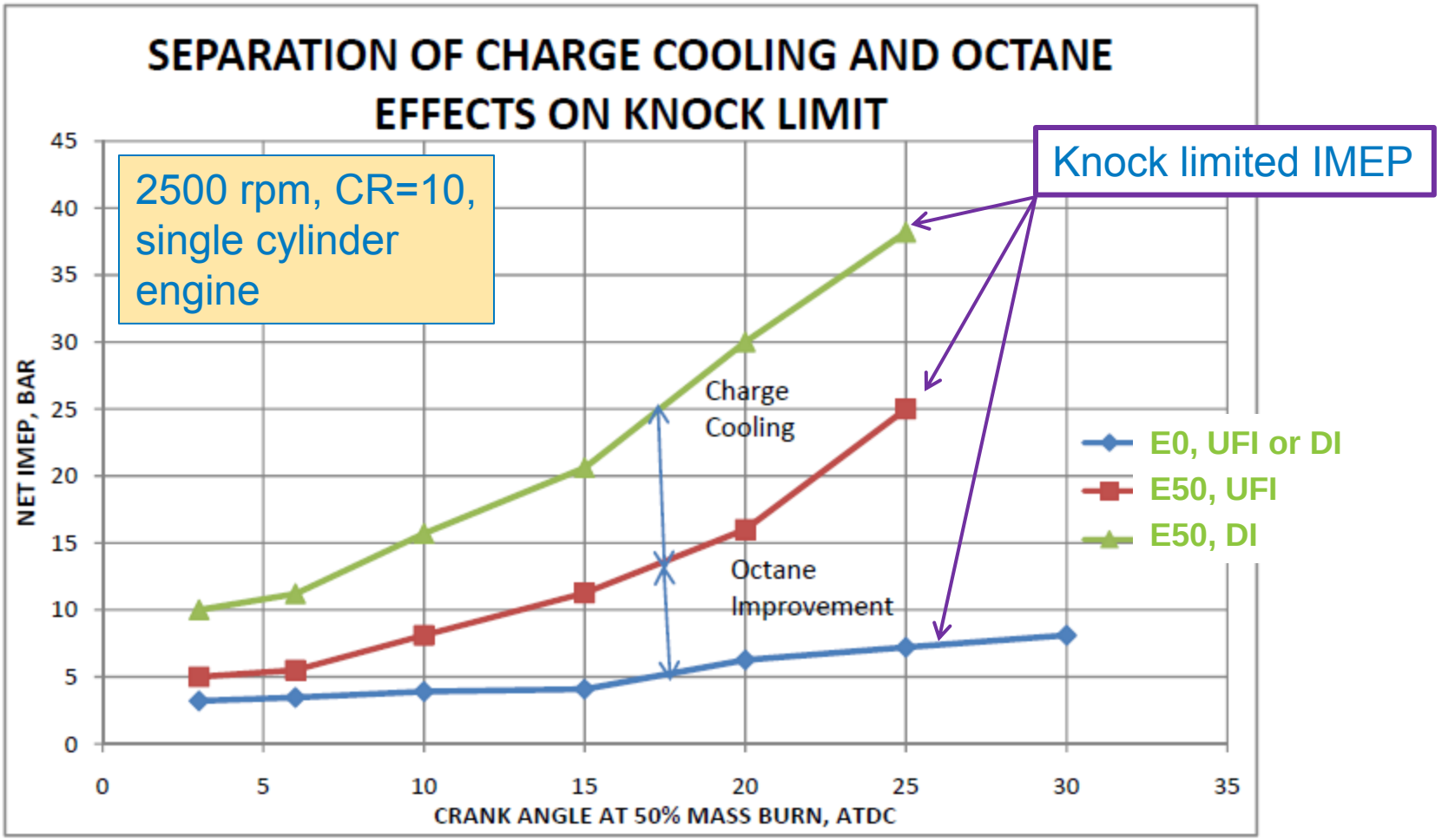
- **Petroleum Equipment Institute Letters Stating Compatibility: http://www.pei.org/PublicationsResources/ComplianceFunding/USTComponentCompatibilityLibrary/tabid/882/Default.aspx**

Efficiency Benefits of Increased CR and RON



CRC Project No. CM-137-11-1b www.crcao.org after Nakata et al., SAE 2007-01-2007

Ethanol has High "Effective" RON

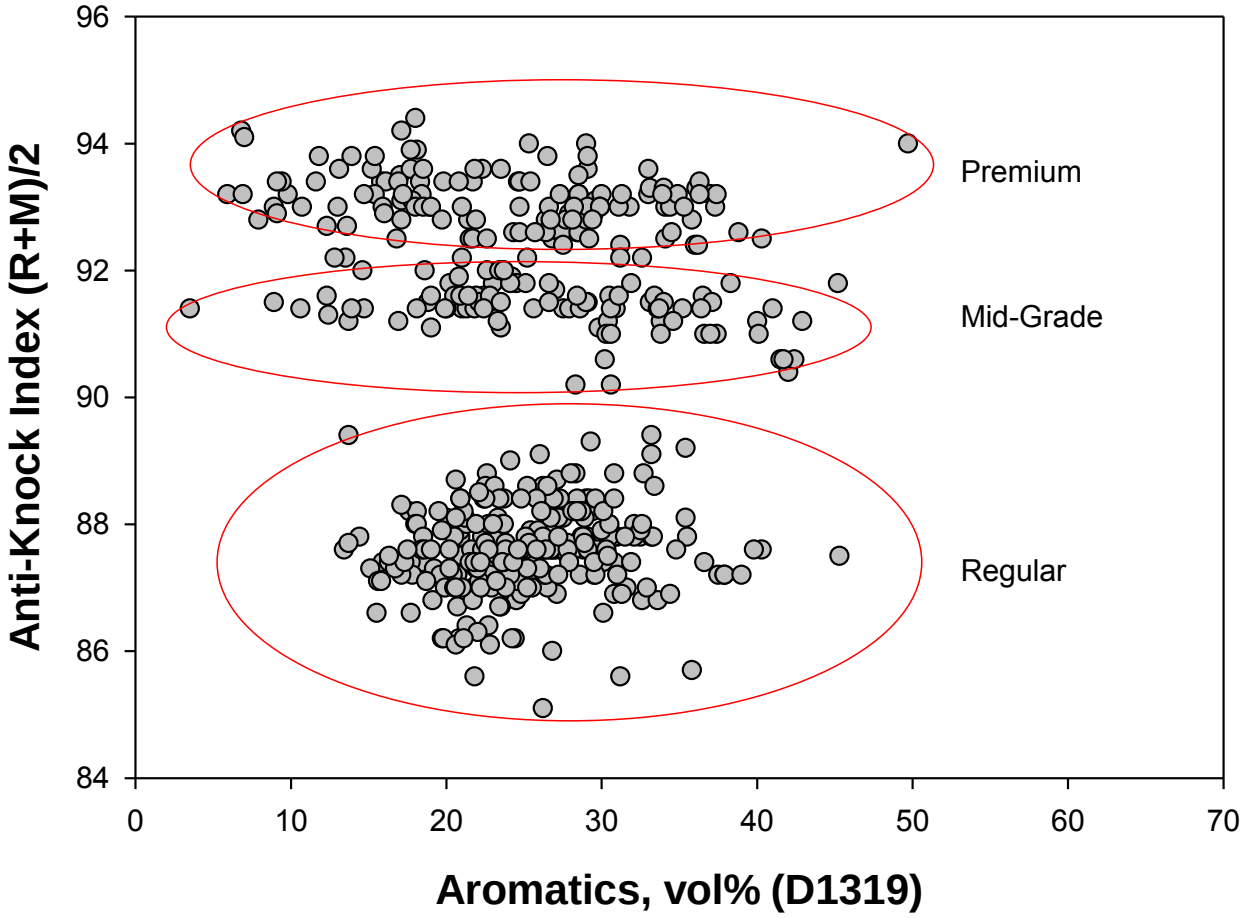


CRC Project No. CM-137-11-1b www.crcao.org after Stein, et al. SAE 2012-01-1277

Other Issues

- **State consumer protection laws**
  - May adopt a version of ASTM standards
  - National Conference of Weights and Measures (NCWM) develops model laws and regulations on fuel quality (NIST HB 130)
  - State laws may forbid use of fuels other than those adopted
- **OEM warranty coverage**
  - Warranties cover defects in materials and workmanship – not problems caused by fuel
  - OEM will not cover fuel problems but typically will say what fuels are acceptable in owner's manual – a marketing advantage
  - Actual voiding of a warranty is a violation of federal law
- **National Fire Protection Association (NFPA) 30 & 30A**
  - May need to be updated to include new fuel
  - Updated every 3 years
- **Renewable Fuels Standard pathway definition**

Aromatics and AKI of US Gasoline



Data from AAM summer 2011 US gasoline survey