SAND2018-6349C

Co-Optimization of
Fuels & Engines

Light-duty Multimode Engine Operation

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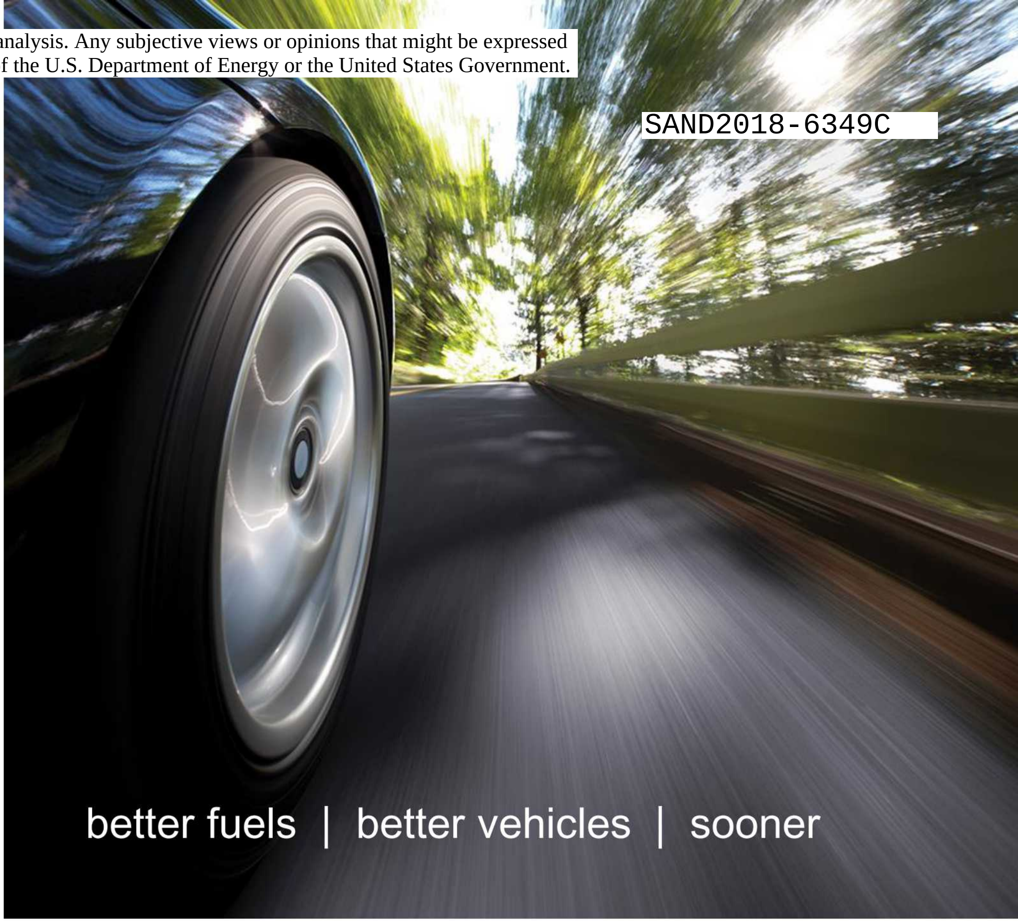
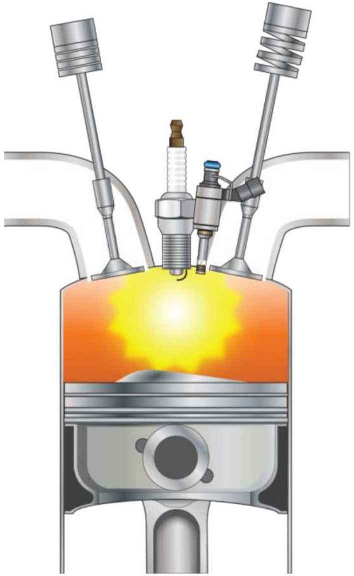


VTO Program Managers: Gurpreet Singh,

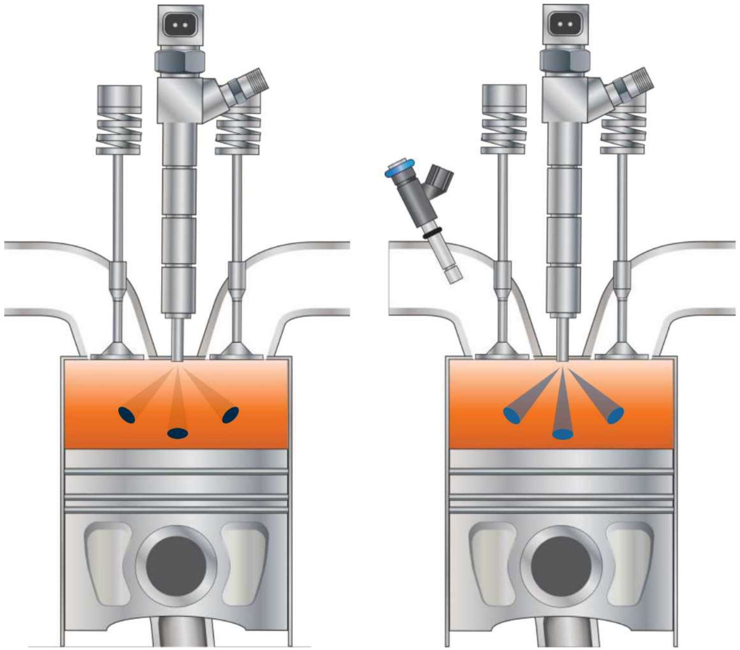
Multi-mode combustion involves use of two or more modes for full coverage of the speed-load map

Spark Ignition (SI)



Low Reactivity Fuel

Advanced Compression Ignition (ACI)



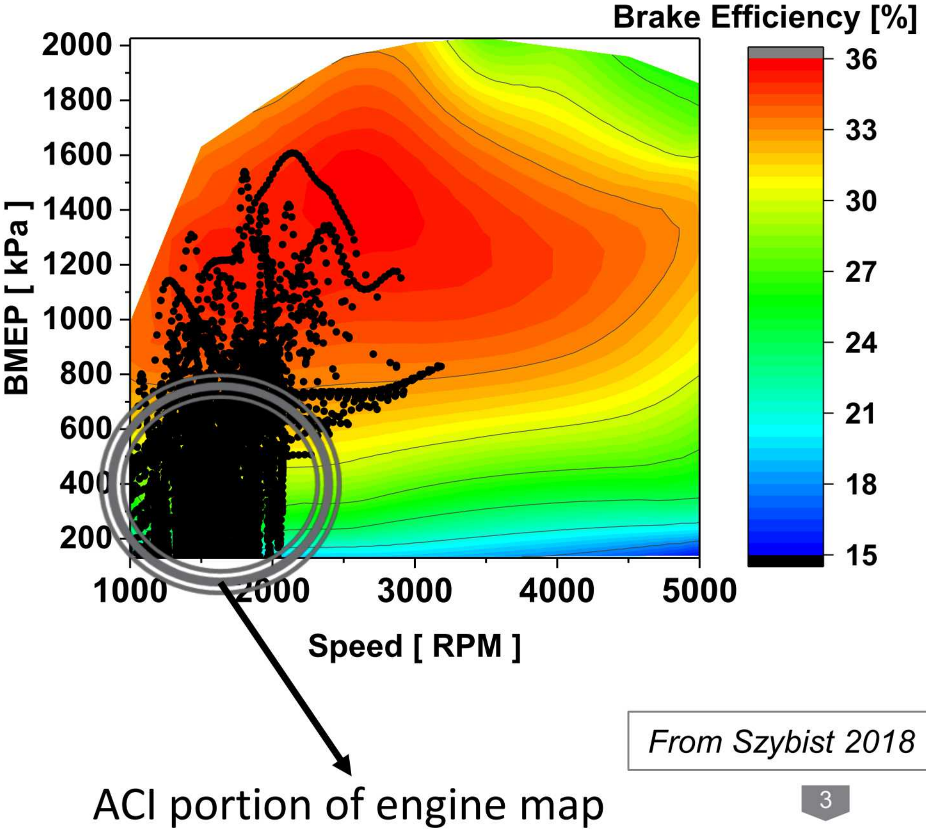
Range of Fuel Properties TBD
(depends on combustion mode)

Mixing Controlled CI

High Reactivity Fuel

Co-Optima Shifting Emphasis of Light Duty (LD) Research from Standalone Boosted SI to Multi-Mode ACI

- Light duty multi-mode efforts combine SI and ACI combustion
  - ACI used at part-load for increased efficiency
  - SI used at high load/speed
- Approach maintains power density/ efficiency gains achieved through downsizing and downspeeding.



From Szybist 2018

Compare “best-in-class” Vehicles with Advanced Combustion

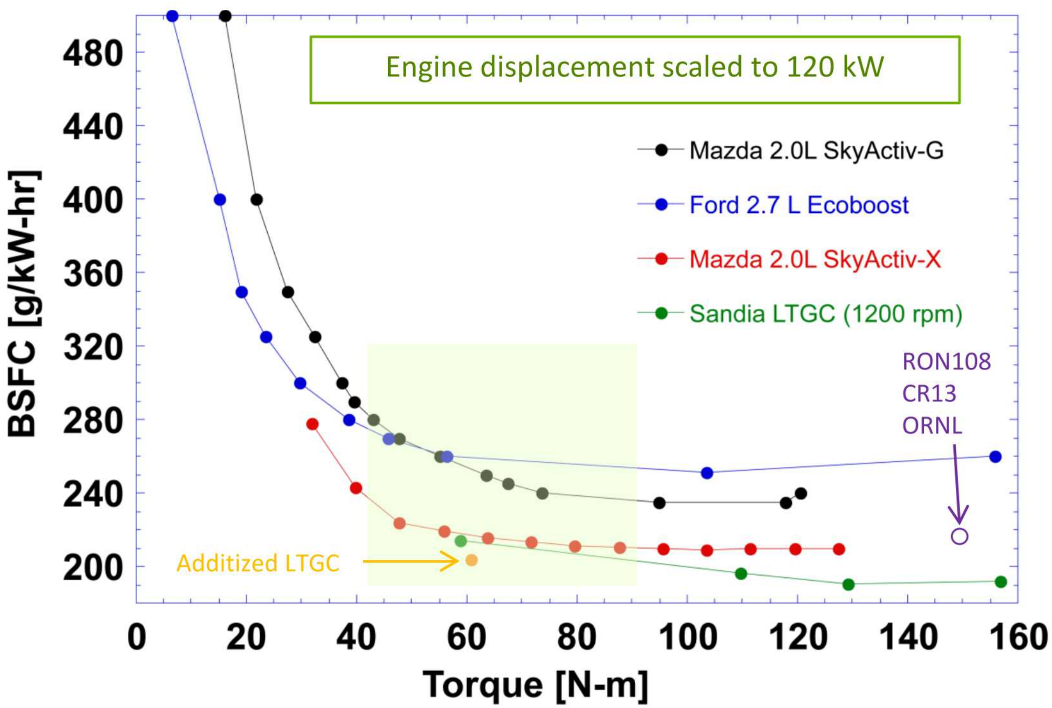
Introduction of...

and

Load Expansion of...

advanced combustion modes can provide substantial fuel-economy benefits.

What fuel properties and market scenarios promote this?



Merit Function Assessment for Mixed-mode Operation

$$
\begin{aligned}
Merit = {} & \frac{(RON_{mix}-91)}{1.6} - K\frac{(S_{mix}-8)}{1.6} \\
& + \frac{0.085[ON/kJ/kg_{mix}]\cdot((HoV_{fuel}/(AFR_{mix}+1))-(415[kJ/kg]/(14.0[-]+1)))}{1.6} \\
& + \frac{((HoV_{mix}/(AFR_{mix}+1))-(415[kJ/kg]/(14.0[-]+1)))}{15.2} + \frac{(S_{Lmix}-46[cm/s])}{5.4} \\
& - H\left(PMI_{mix}-1.6\right)\left[0.7+0.5(PMI_{mix}-1.4)\right] + 0.008°C^{-1}\left(T_{c,90,conv}-T_{c,90,mix}\right)
\end{aligned}
$$

- Developed for stoichiometric boosted SI engine operation.
- Going forward: re-assess Merit Function for mixed-mode operation.
- What is considered a benefit for boosted SI, could be a detriment for mixed-mode operation.

Approach to Multimode Research

Many different part-load ACI approaches are candidates for multi-mode approach:

- NVO HCCI, exhaust re-breathe HCCI
- Spark-assisted CI (e.g., Mazda SPCCI)
- Gasoline compression ignition (GCI)
- Low temperature gasoline combustion (LTGC)

SPCCI = spark plug controlled compression ignition
NVO HCCI = Negative valve overlap homogeneous charge compression ignition

A multi-mode approach can include non-CI combustion modes:

- Lean well-mixed SI.
- Lean stratified-charge SI has high efficiency potential.

Avoid picking a winner has advantages.

Trying to structure a research program that identifies fuel property and engine parameter impacts relevant to ALL part-load ACI approaches as well as competing approaches (variable CR engine, lean-burn SI, etc.).

US DRIVE - ACEC LTC Research Priorities

Highest priorities for low-temperature combustion:

a. Expanded speed and load range

b. Reduced engine out HC and CO emissions

c. Lower combustion noise

d. Simpler transient control/combustion mode switching

e. Improved cold operation

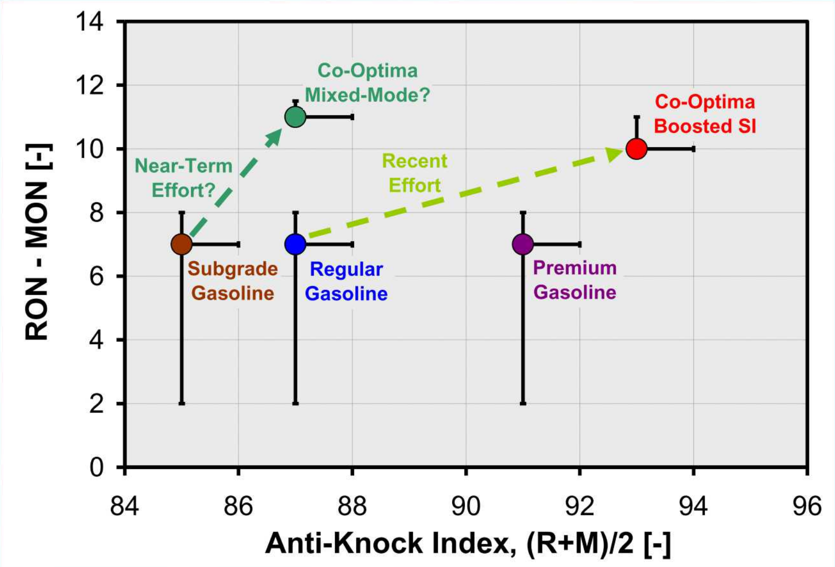
f. Increase tolerance to changes in ambient temperature and humidity, and **market fuel variability**

g. Reduce cost of lean-NO_x aftertreatment system

h. Research that reduces the content, complexity, and cost of engines while increasing efficiency to enable a higher penetration of hybrid electric vehicles

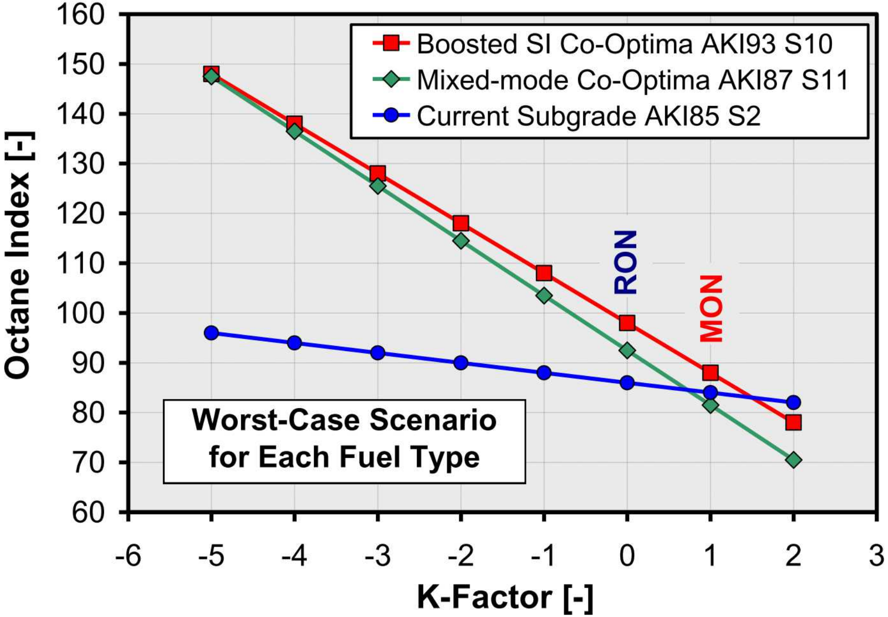
Fuels Scenarios

- Engine design is limited by “worst” fuel in the intended market.
- Idea: Ban low-S fuels for use in newer vehicles.



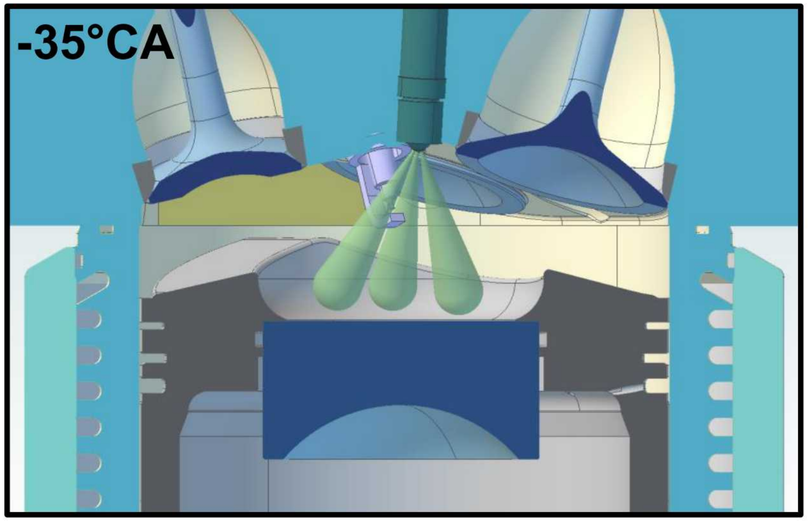
- High-S AKI87 fuel looks attractive.

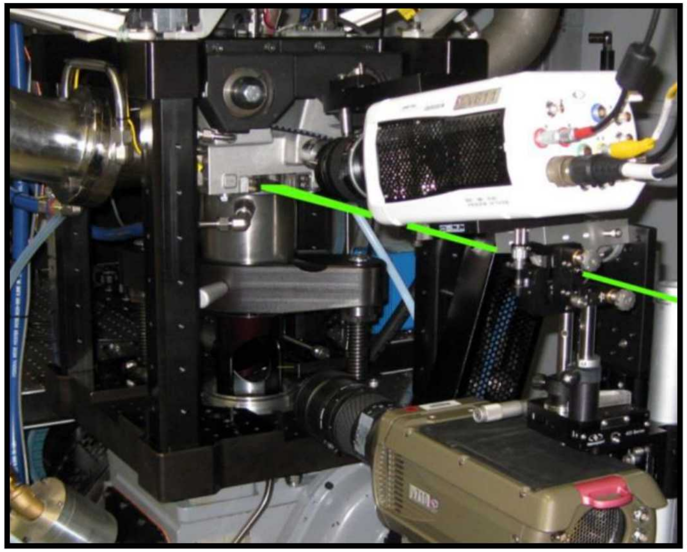
$$OI = RON - K \bullet S$$



Sandia Alternative Fuels DISI Engine Lab

- Drop-down single-cylinder engine. Bore = 86 mm, Stroke = 95 mm, 0.55 liter, CR = 12.
- Piston bowl and closely located spark and injector.
  - Highly relevant for stratified operation. 8-hole injector with 60° included angle.
- Identical geometry for all-metal and optical configurations
  - Minimal discrepancy between performance & emissions testing and optical tests.





- Apply a range of high-speed optical diagnostics:
  - PIV – Flows, Mie - Liquid Spray, RIM - Wall Wetting, IR - Fuel Vapor. Plasma & flame imaging.

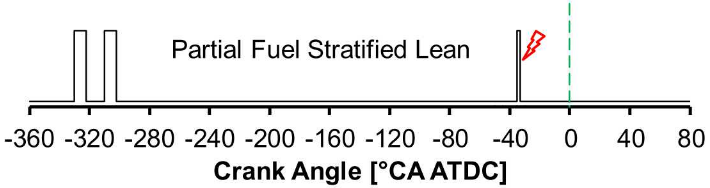
Fuels Matrix used in Alt. Fuels DISI Engine Lab

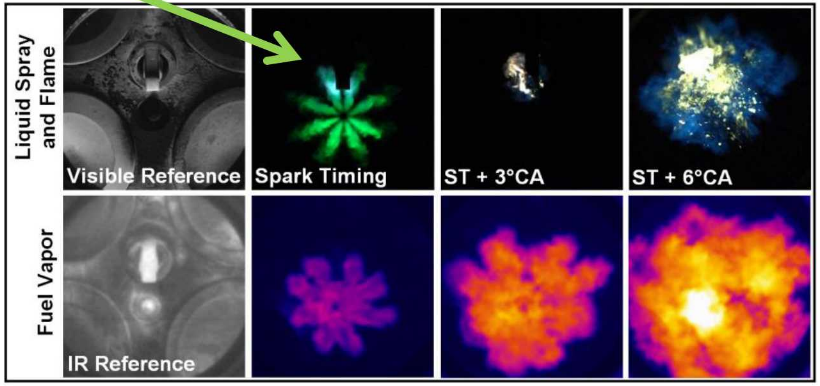
- Here, study eight RON = 98 fuels, and one regular E10 gasoline.
  - Combustion modes: Stoichiometric, lean well-mixed, and lean stratified.
- Octane sensitivity, composition, HoV, end-boiling point, and PMI vary greatly.
- Future: Expand to include lower-RON fuels for lean mixed-mode combustion.

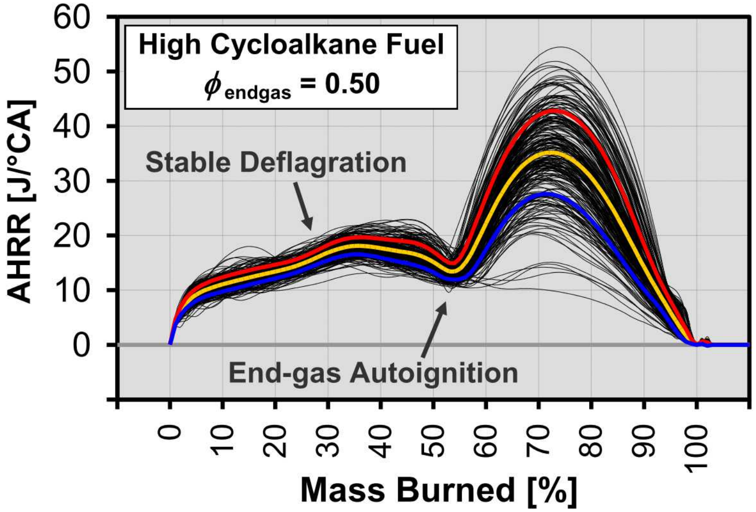
		Co-Optima Core Fuels							
	E10 RD5-87	**Alkylate**	**E30**	**High Aromatic**	**High Olefin**	**High Cycloalkane**	**Isobutanol Blend**	**2-Butanol Blend**	**Diisobutyl-ene Blend**
RON	90.6	98.0	97.9	98.1	98.3	97.8	98.1	98.2	98.3
MON	83.9	96.7	87.1	87.6	87.9	86.9	88.0	89.1	88.5
Octane Sensitivity	6.7	1.3	10.8	10.5	10.4	11.0	10.1	9.1	9.8
AKI	87.3	97.3	92.5	92.8	93.1	92.3	93.1	93.7	93.4
Oxygenates [vol.%]	10.6	0.0	30.6	0.0	0.0	0.0	24.1	28.4	0.0
Aromatics [vol.%]	22.8	0.7	13.8	39.8	13.4	33.2	19.0	17.9	20.1
Alkanes [vol.%]	48.7	98.1	40.5	46.2	56.4	40.6	53.1	50.1	56.3
Cycloalkanes [vol.%]	12.1	0.0	7.0	8.0	2.9	24.2	0.0	0.0	0.0
Olefins [vol.%]	5.9	0.1	5.6	4.5	26.5	1.6	3.8	3.6	23.6
T10 [°C]	57	93	61	59	77	56	63	63	63
T50 [°C]	98	100	74	108	104	87	-	-	-
T90 [°C]	156	106	155	158	136	143	111	111	111
Net Heat of Combustion [MJ/kg]	41.9	44.5	38.2	43.0	44.1	43.2	40.6	40.1	43.2
Heat of Vaporization [kJ/kg]	412	308	532	361	333	373	412	415	337
AFR Stochiometric	14.1	15.1	12.9	14.5	14.8	14.5	13.8	13.6	14.7
HoV [kJ/kg stoichiometric charge]	27.3	19.1	38.4	23.3	21.1	24.0	27.9	28.5	21.5
Particulate Matter Index	1.68	0.22	1.28	1.80	1.00	1.54	0.40	0.37	0.47

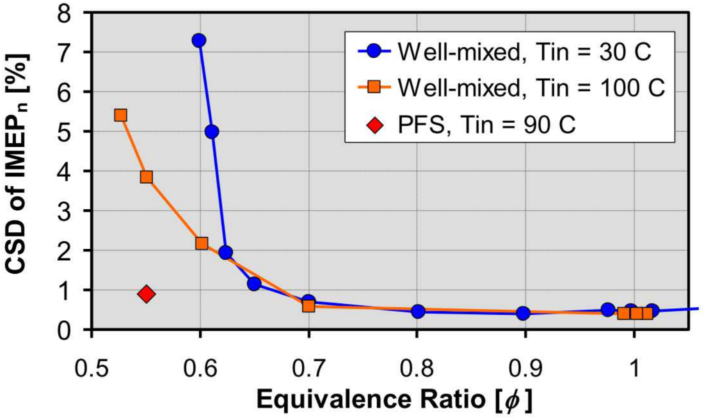
Example of Results: Lean Mixed-Mode Combustion

- Similar to Mazda's Active-X approach.
- Established stratification approach to stabilize ultra-lean mixed-mode combustion.
- Use strong CA50 control authority to achieve stable end-gas autoignition for CA10-90 < 30 ° CA
  $\Rightarrow$ 20% relative efficiency gain.



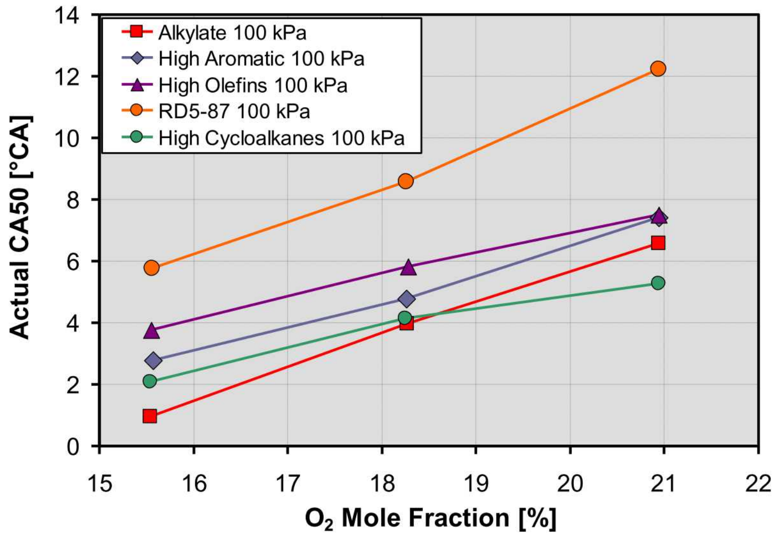


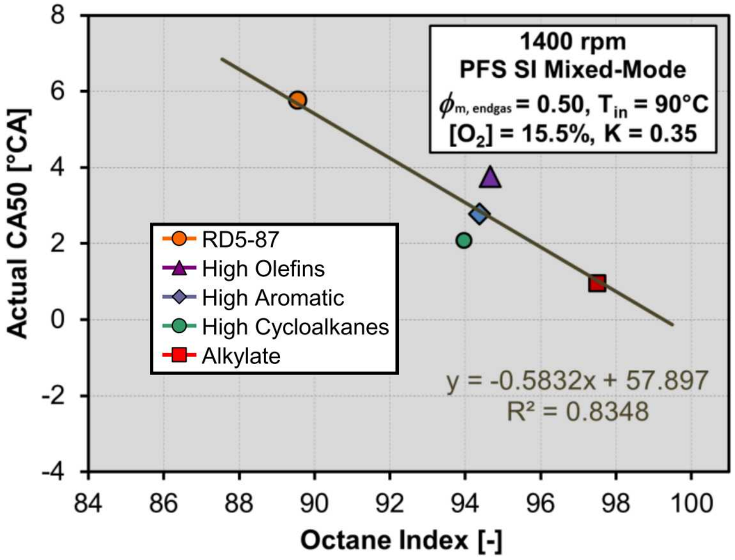




Fuel Effects for Mixed-Mode Combustion

- 8 – 13% trapped hot residuals can be used achieve required reactant temperature and facilitate mixed-mode combustion.
  - Reactant $[O_2]$ would be affected.
- The fuels show different sensitivities to $[O_2]$.
  - Using CHEMKIN to clarify reasons.





- Octane Index appears applicable for rank ordering fuels.
- Future work will add alcohols to test matrix.

Acknowledgement

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