



Multifuel Compatibility and SwRI's Fuel-SPOT™

SOUTHWEST RESEARCH INSTITUTE®

Imad Khalek, PhD, FSAE

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Motivation

- Increasing demand in market for biomass-based diesel fuels
 - State programs (CARB LCFS and others)
 - Recent EPA RFS revisions
 - Corporate sustainability goals
- Drive towards higher blends of biodiesel and renewable diesel fuel
 - Different fuels can present both challenges and opportunities for engine performance and emissions
- It is possible to deal with challenges and take advantage of opportunities through engine calibration...IF we can detect the presence of different fuels

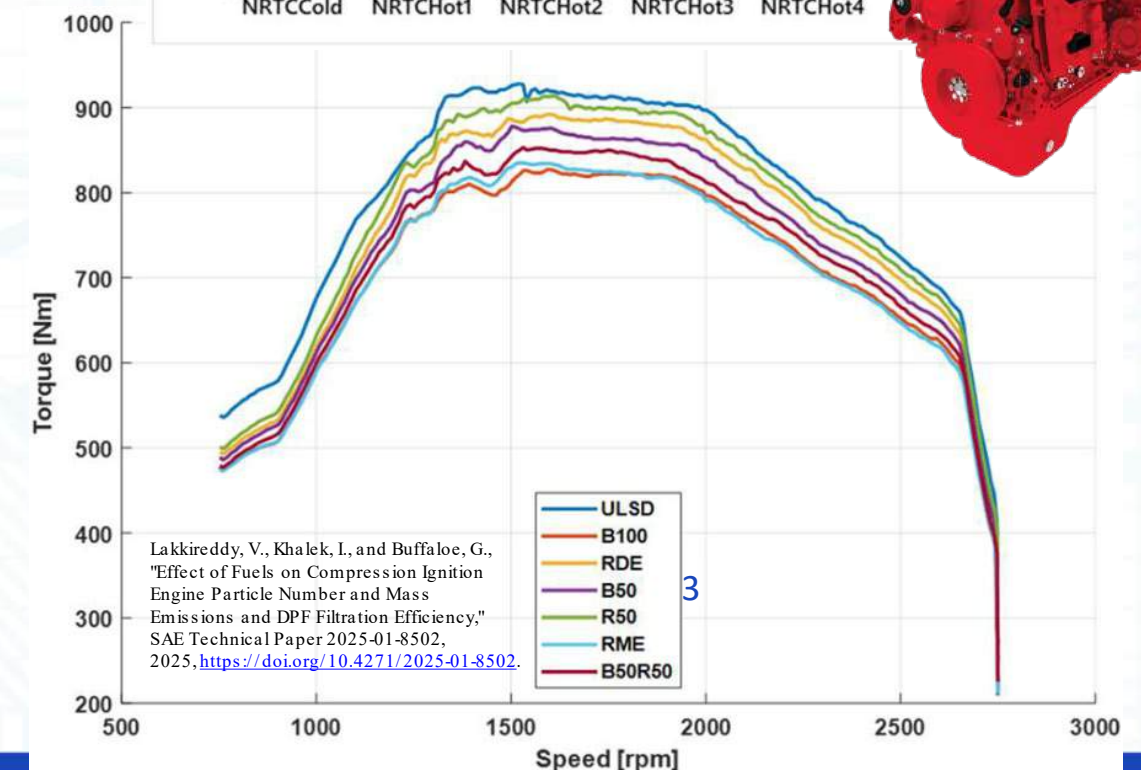
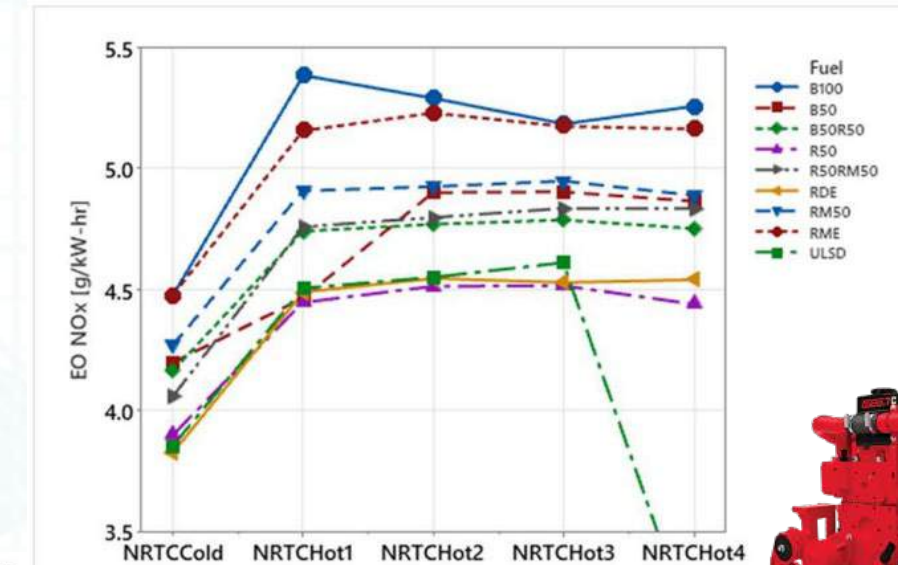


Bio & Renewable Diesel Effects on Engine Performance

As the popularity and availability of bio and renewable diesel fuels has increased, a number of studies have been conducted to understand the effect of these fuels on engine and aftertreatment performance.

Decreases of 12-15% in torque and increases of 15-20% in engine out NO_x have been observed.

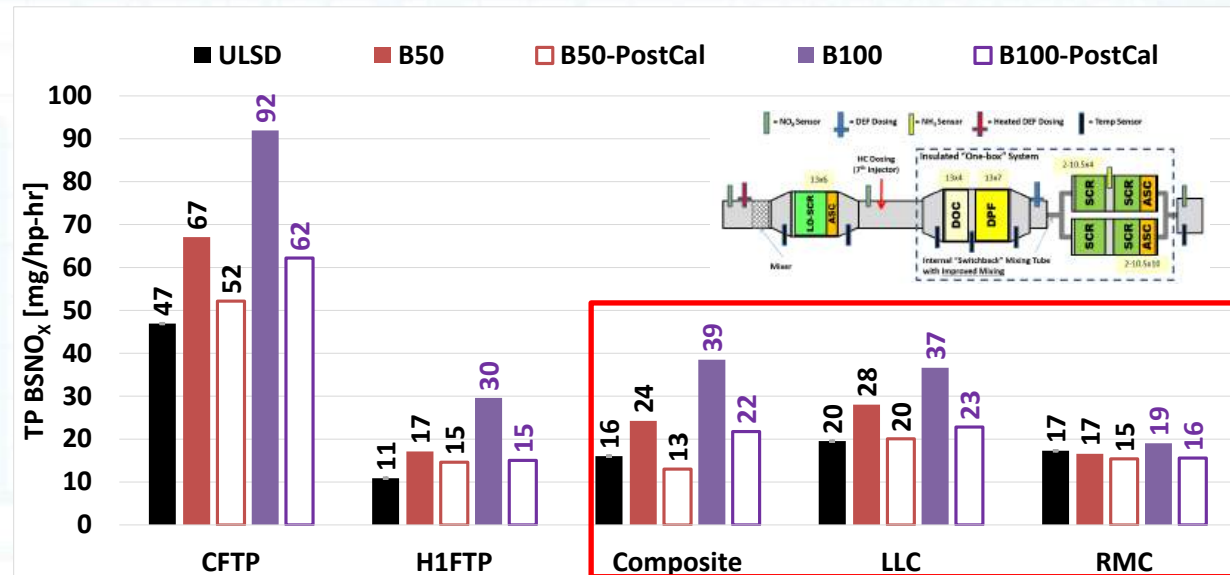
These performance shifts may be unacceptable to customers and will have implications on warranty and emissions compliance.



Lakkireddy, V., Khalek, I., and Buffaloe, G., "Effect of Fuels on Compression Ignition Engine Particle Number and Mass Emissions and DPF Filtration Efficiency," SAE Technical Paper 2025-01-8502, 2025, <https://doi.org/10.4271/2025-01-8502>.

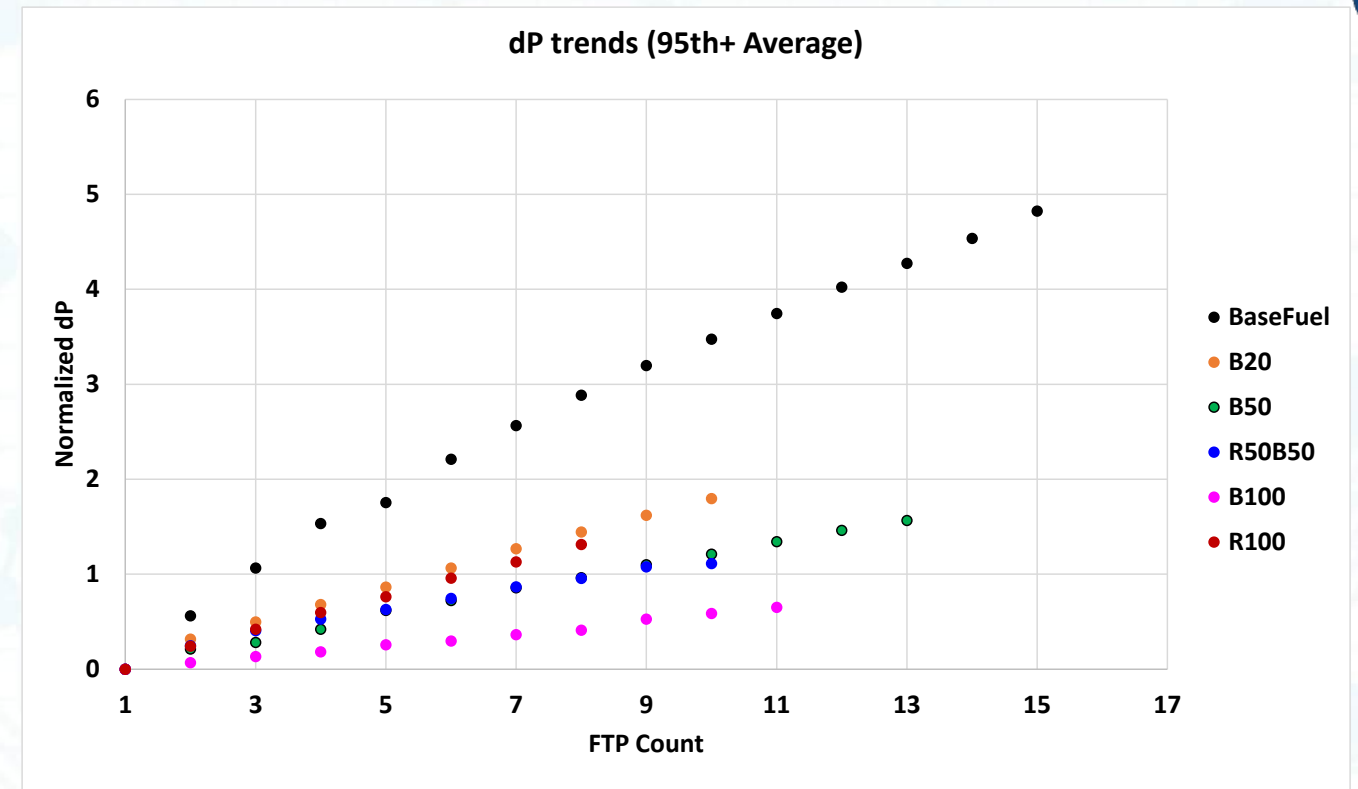


Challenges and Opportunities with Biomass-Based Fuels



Note: 2027 EPA Standard is 35 (50 for LLC)

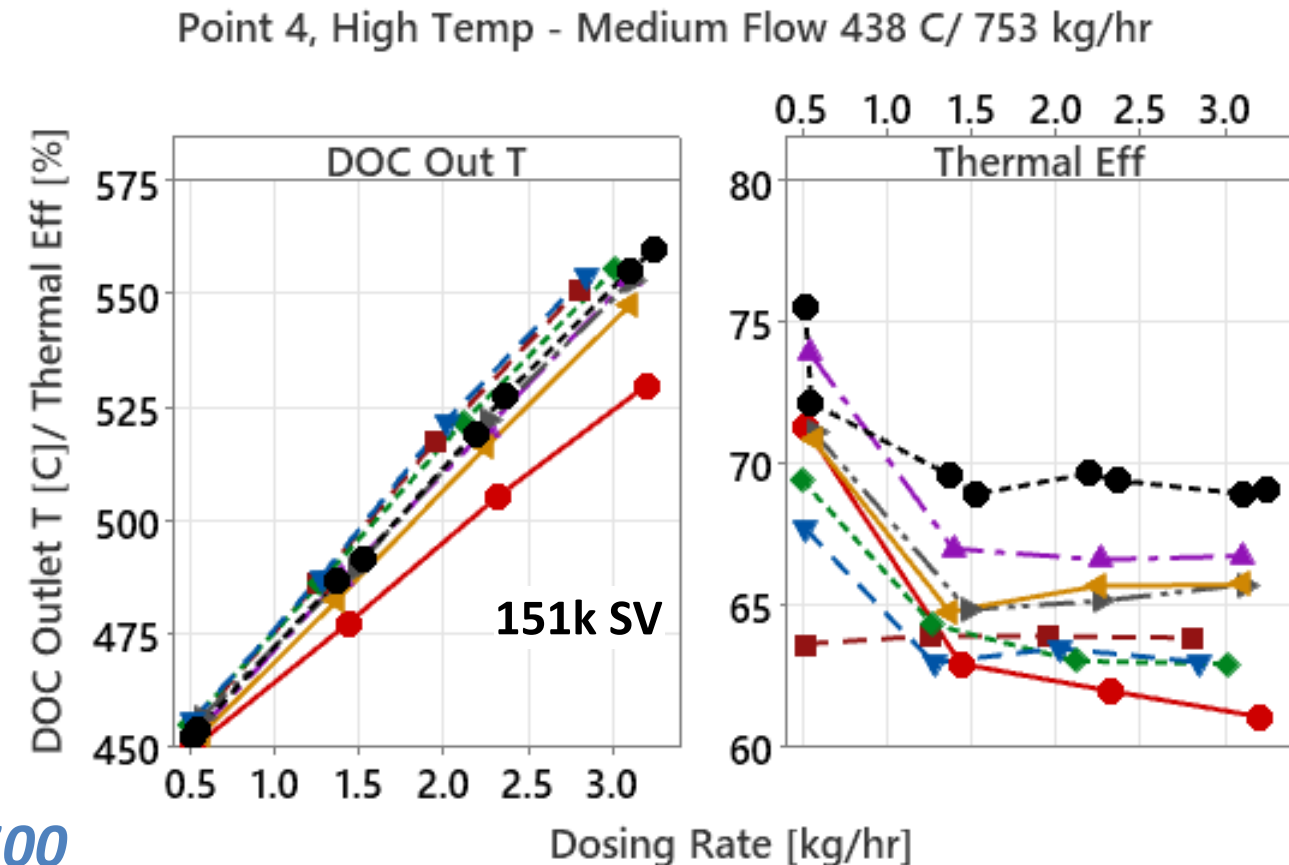
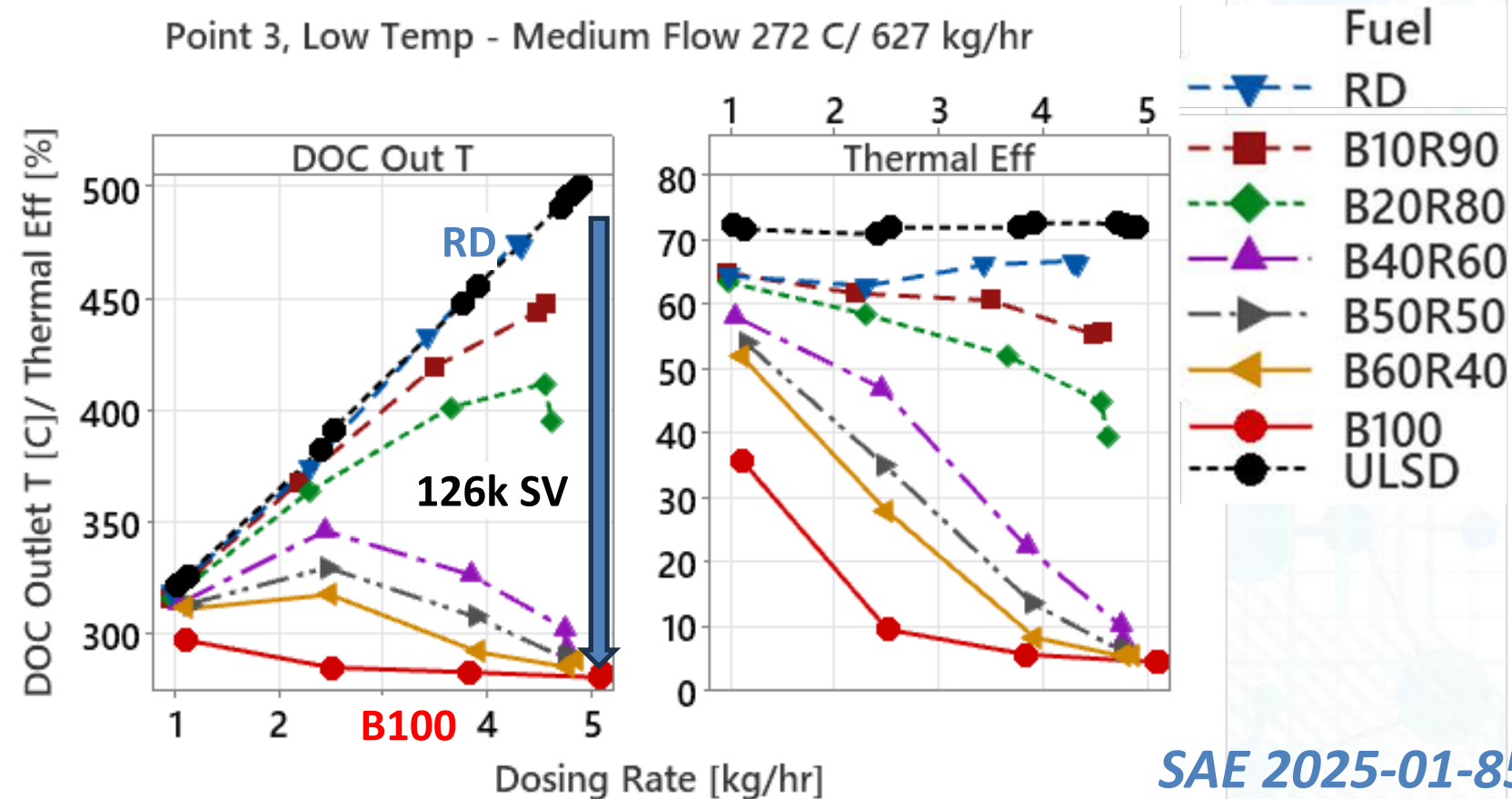
- B50 and B100 Blends on Stage 3 Low NO_x Engine showed higher NO_x
- NO_x equivalent to diesel after recalibration
- Biodiesel specific recalibration can adapt IF fuel change can be sensed



- Reduced DPF loading and dP trend with biodiesel and renewable diesel

Current effort – impact of potential biofuel metals/phosphorous contamination on 2027 AT systems...do fuels specs need updating ?

High Biodiesel Blend Impact on DOC Exotherm for Regeneration



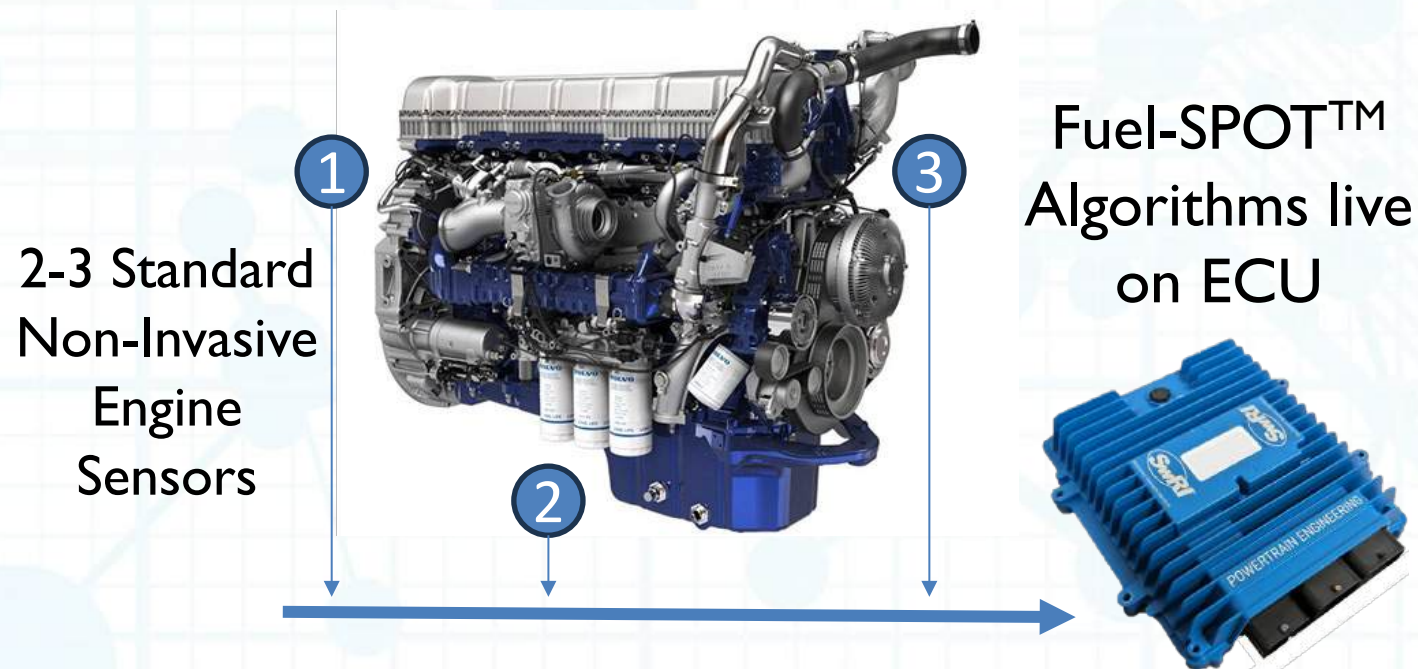
- Thermal efficiency decreases as B100 fraction in fuel increases.
- Fuel quenching occurs at lower dosing rate as B100 fraction in fuel increases.
- Poor oxidation at even as low as B40R60 at higher dosing rates.

- The differences between fuels appear to be small but progressively increase with increase in biodiesel fraction in blend.

Fuel-SPOT™ Technology Development

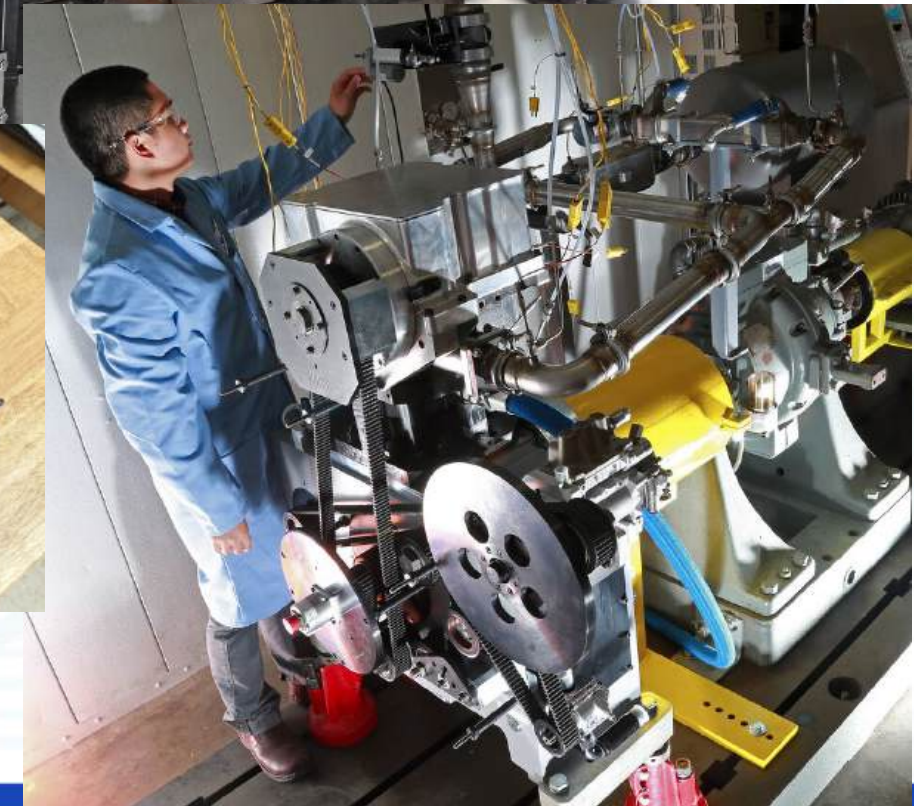
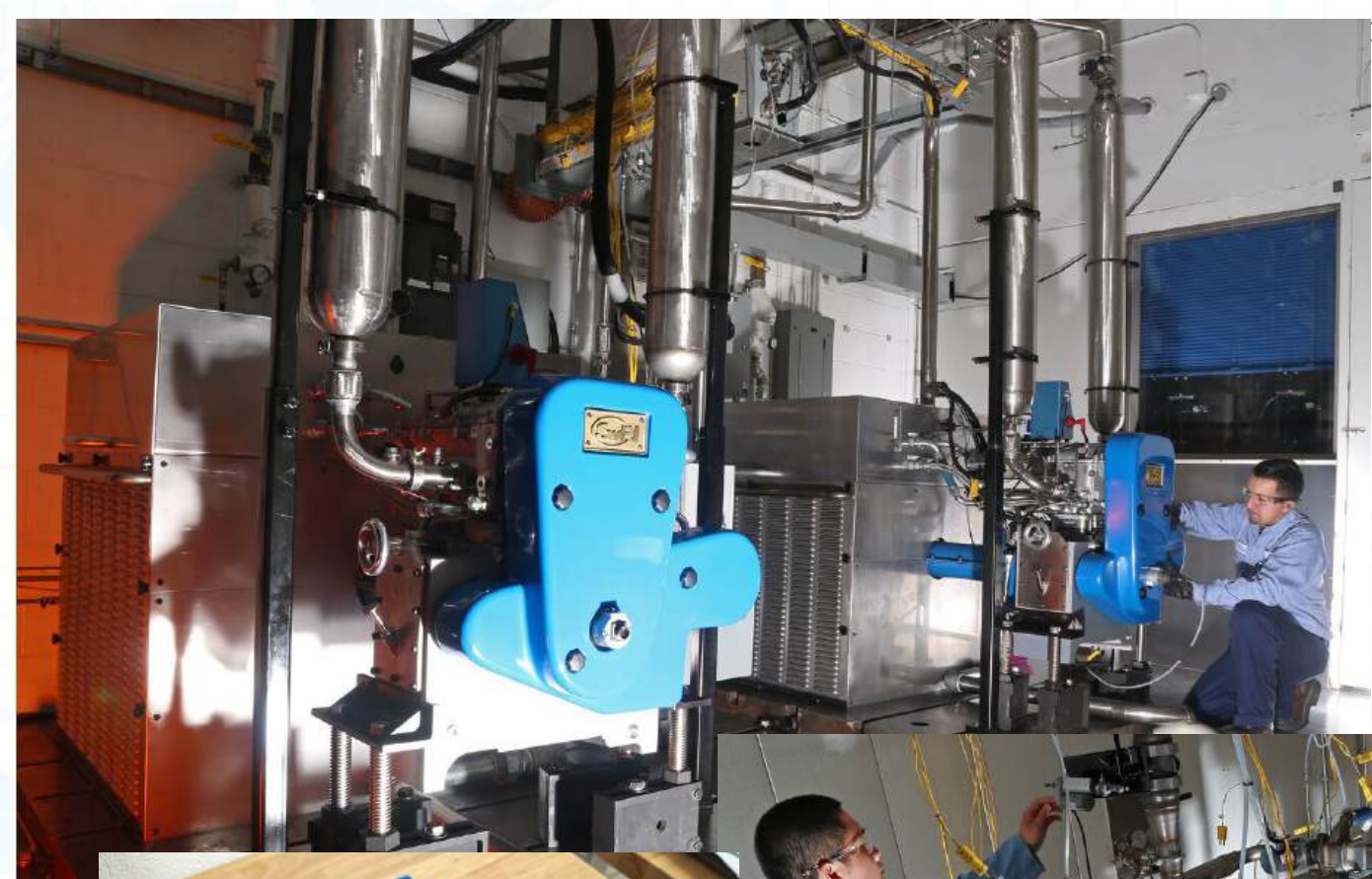


- SwRI used Internal Research funding to develop technique for classifying fuels by using standard engine off the shelf sensors (Patent Pending)
- Validated on neat fuels and 50/50 blends
- Advanced Machine Learning techniques (SVM) are applied to identify decision boundaries for classification of fuels



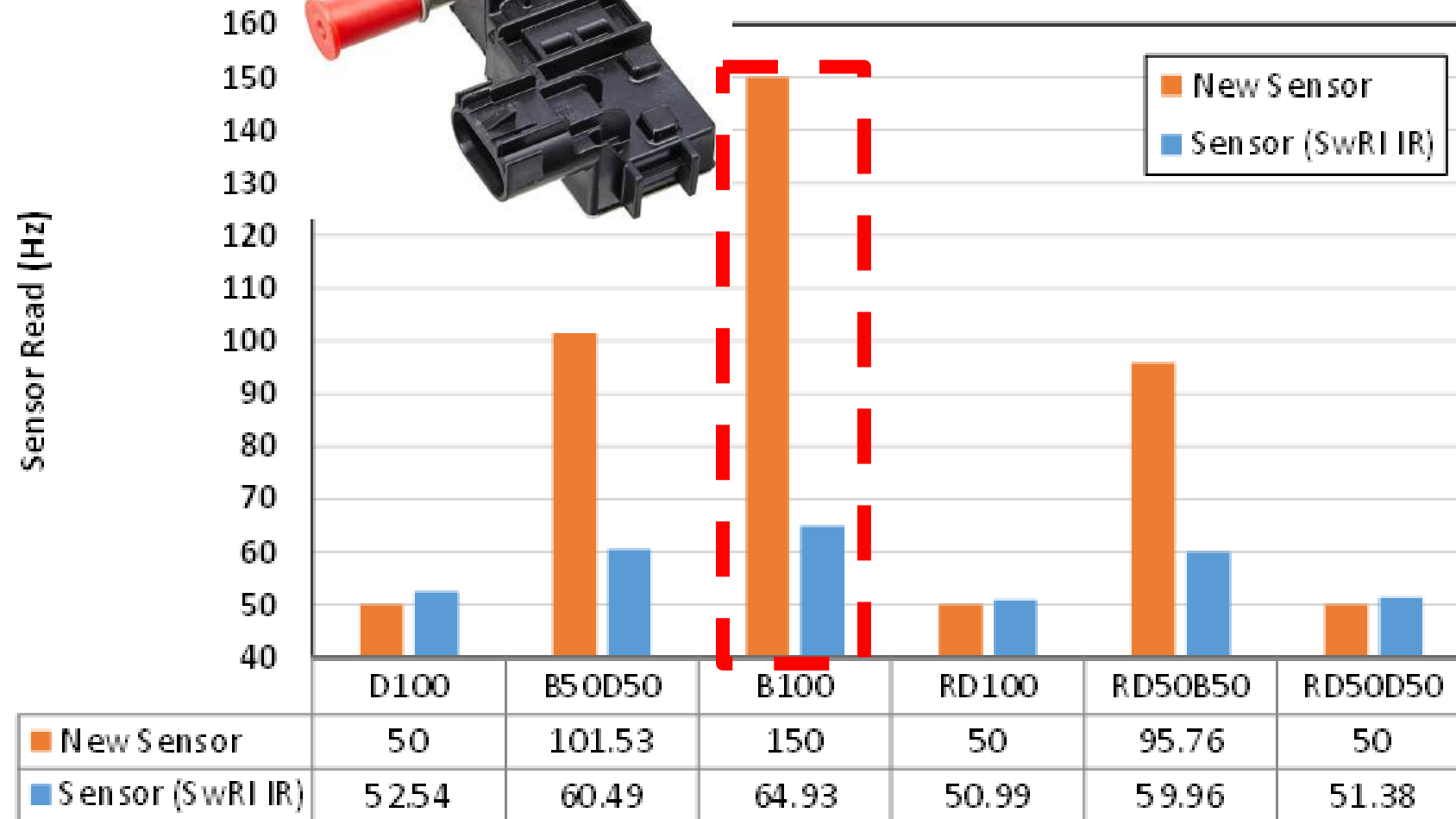
General Approach

- Identify Potential Sensors
 - Proposed:
 - Flex-Fuel sensor (ethanol)
 - Knock Sensor
 - Crank position sensor (acceleration and/or torsionals)
- Statistical Modeling
- “Sensor Fusion” – multiple information streams combined into one decision making algorithm



In-Line Flex Fuel Sensor

Flex-fuel sensor used in
E85 vehicles



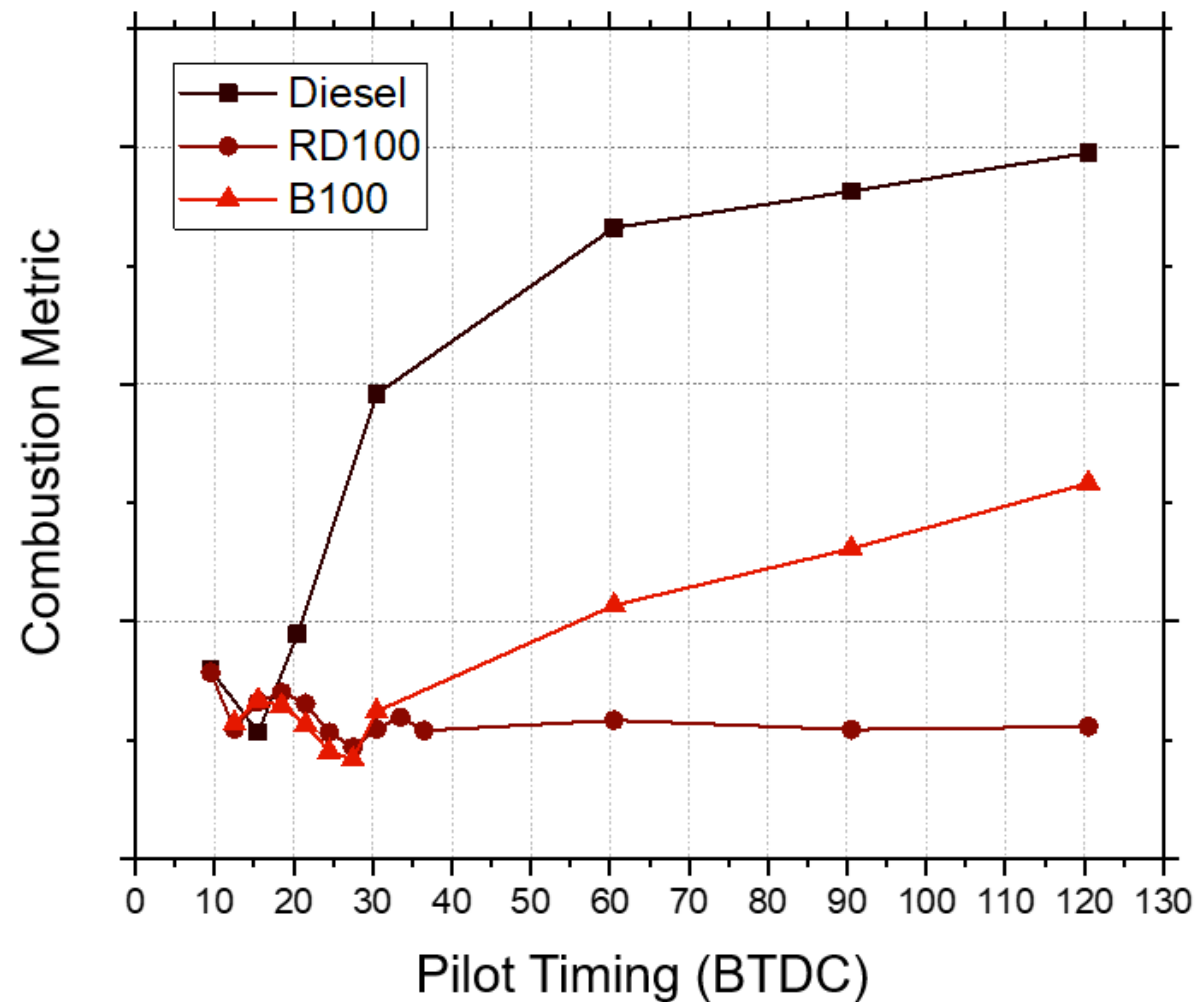
New Sensor (Orange) = Updated Sensor
Sensor (Blue) = Production Flex Fuel Sensor

- Use of a dielectric sensor to detect fuel chemistry, like with flex fuel ethanol vehicles
- Clear differentiation of biodiesel content in either 2D Cert Fuel (D) or Renewable Diesel (RD)
- No differentiation of RD versus Diesel
- This is excellent information, but more is needed to robustly identify a range of fuels



Flex fuel sensor $\approx$ oxygen detection

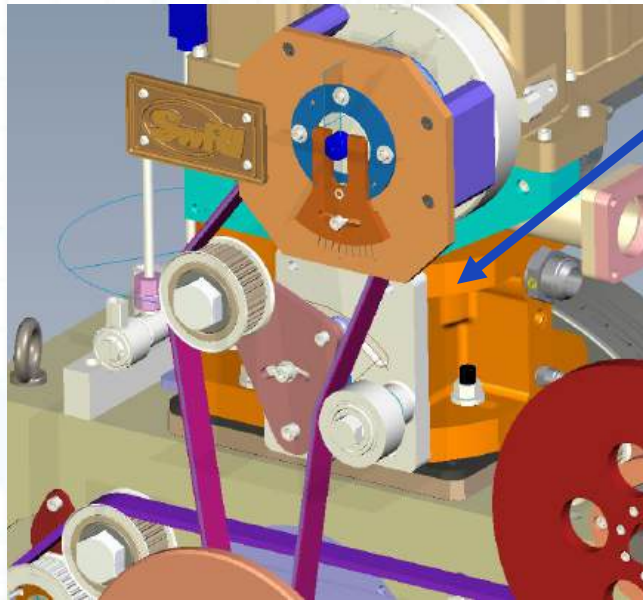
Fuel Cetane Sensing Using Pilot Behavior



Pilot Sweep ~ Fuel Cetane Sensing ?

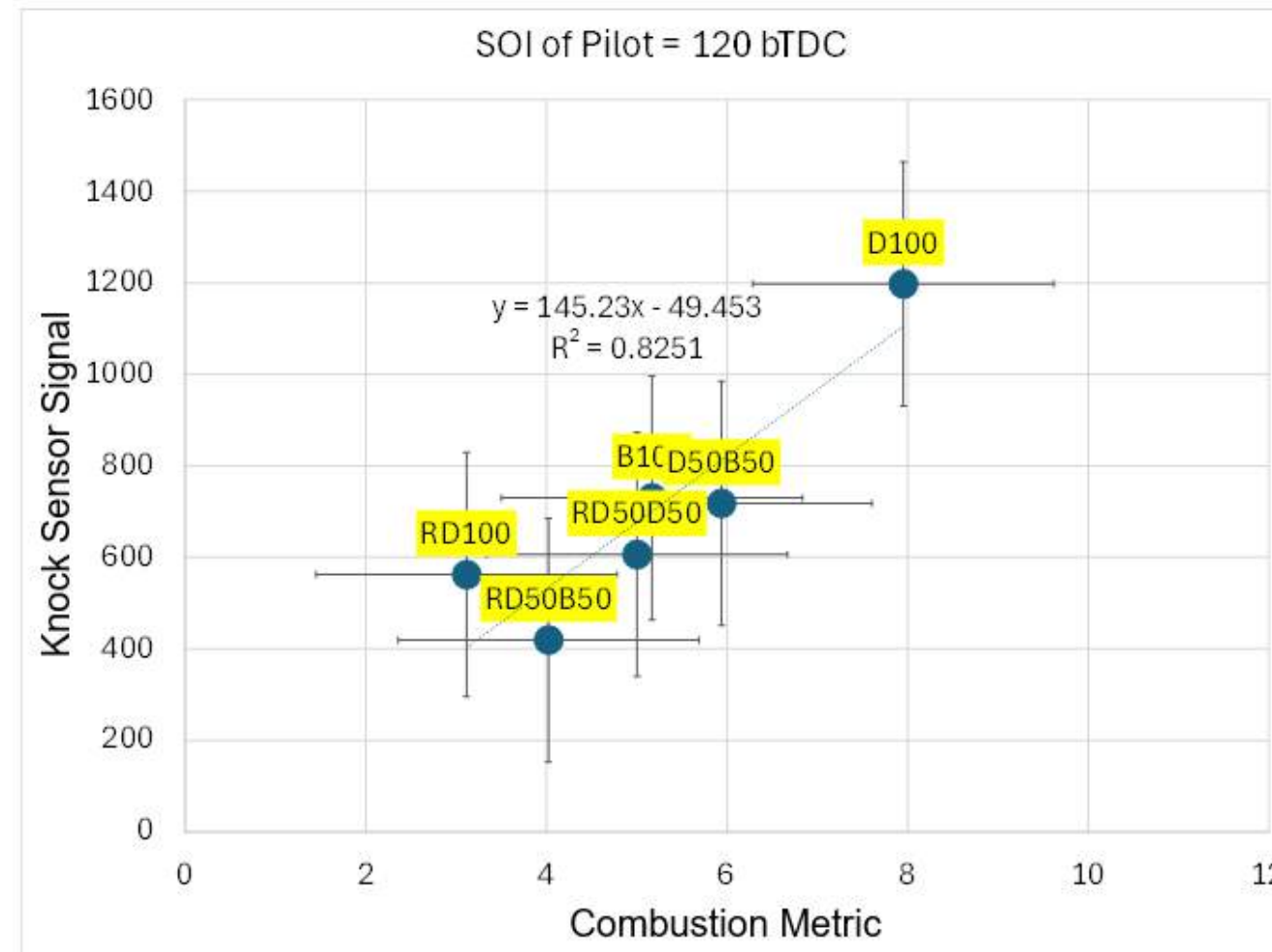
- Deliberate pilot timing sweep (possibly after re-fueling with suitable delay)
- Note behavior is different with different Cetane Number
 - RD100 >> B100 > Diesel
- Possible metrics
 - Separation at 120°BTDC
 - Shape of sweep curve
- This can detect significant changes in fuel ignition delay
 - How much resolution ?
 - How do we detect this combustion metric on engine without cylinder pressure ?

Pilot Metric vs Knock Sensor Vibration



Knock sensor mounted
near top firing deck

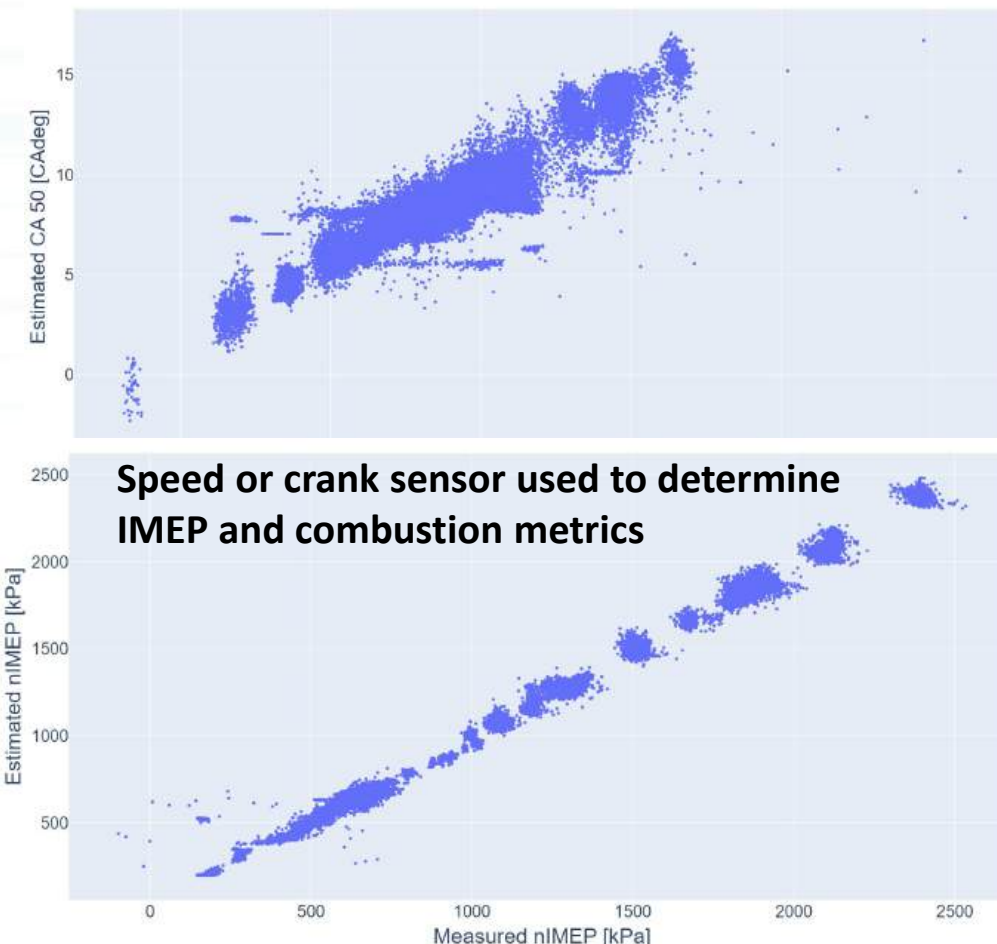
Knock sensor + Pilot Sweep ~
Fuel Cetane Sensing



- Signal from knock sensor was good enough to sense presence or absence of pilot event and larger changes in strength
- A good indicator from significant fuel changes, but not enough by itself...

Crank Position Sensor: Combustion Analysis

- Fit networks with 1 CA° and 6 CA° crank resolutions
- Used Tensorflow to fit deep neural network
- Cycles were randomly split into training (80%) and test (20%) data sets
- Applied to CA 50, CA 10, CA 10-90, nIMEP, Peak Pressure, Peak Pressure location, and MRPR location
- New analysis (not shown in table) using neural network approach can identify CA2 when considering input such as start of injection (SOI) from ECU



Crank speed sensor ≈ torque detection

Resolution		CA 50 [CAdeg]	CA 10 [CAdeg]	MFB 10-90 [CAdeg]	nIMEP [kPa]	Peak P [kPa]	MRPR [kPa/CAdeg]
1 CA°	R2 Test	0.899	0.834	0.695	0.994	0.992	0.874
	R2 Train	0.902	0.843	0.699	0.994	0.992	0.883
6 CA°	R2 Test	0.888	0.763	0.579	0.997	0.991	0.743
	R2 Train	0.889	0.771	0.575	0.997	0.991	0.743



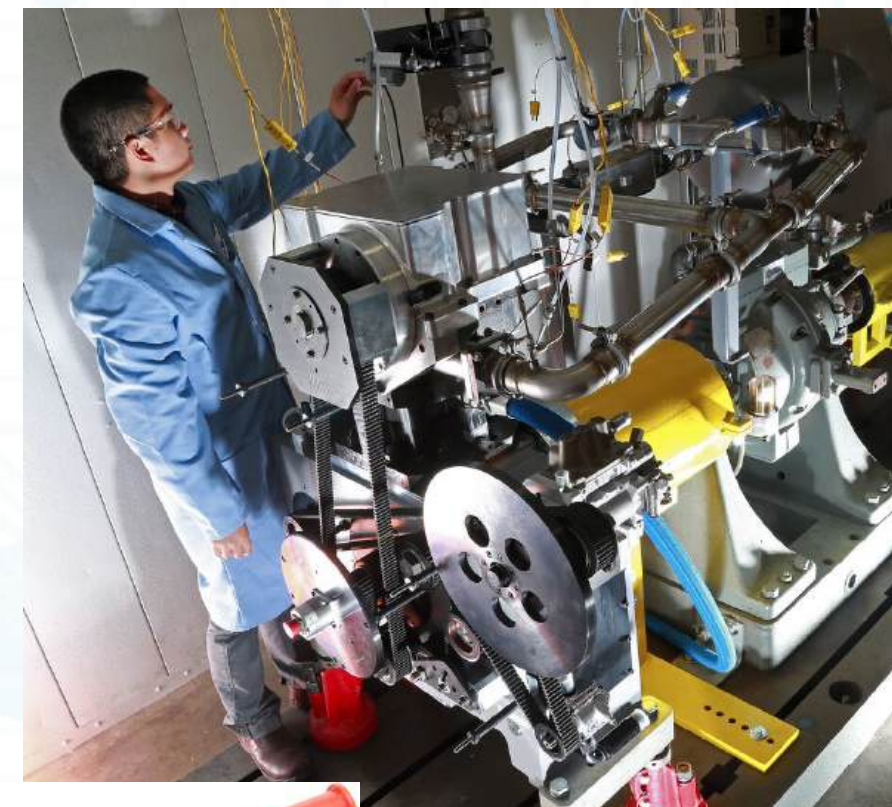
Other Methods for Fuel Energy Content

- Many diesel engines already employ various sensing methods using crank-speed sensor for cylinder balancing / injector calibration
 - Idle cylinder cutouts on some 4-cylinder engines
 - Fuel injection during motoring events
 - Others...
- These methods could also be deployed for sensing a change in fuel energy content after re-fueling events
 - Good information but not enough by itself...
 - How much resolution ?

Crank speed sensor $\approx$
Energy Content
Detection

Sensor Study Summary

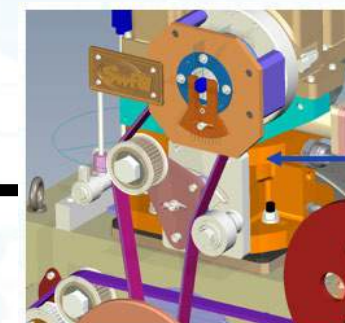
- SwRI used the HD SCE to validate production sensors with advanced signal conditioning could be used to detect changes in combustion associated with fuel properties
- Approach later validated on multi-cylinder engine platforms



Flex fuel sensor $\approx$ oxygen detection

Knock sensor $\approx$ cetane detection

Crank speed sensor $\approx$ fuel energy detection



Development Platforms

2.2L



6.7L



I5L



6.8L

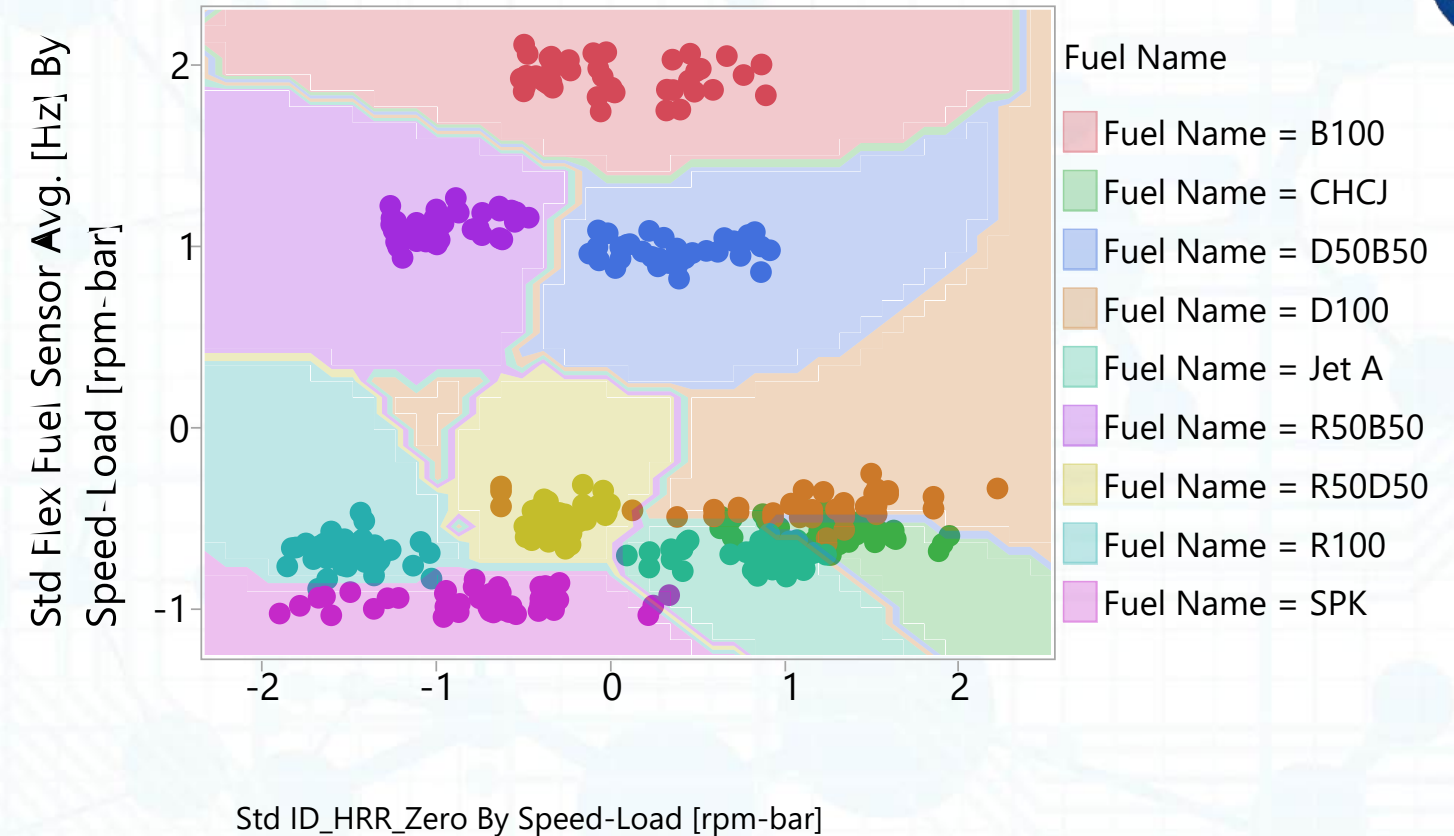
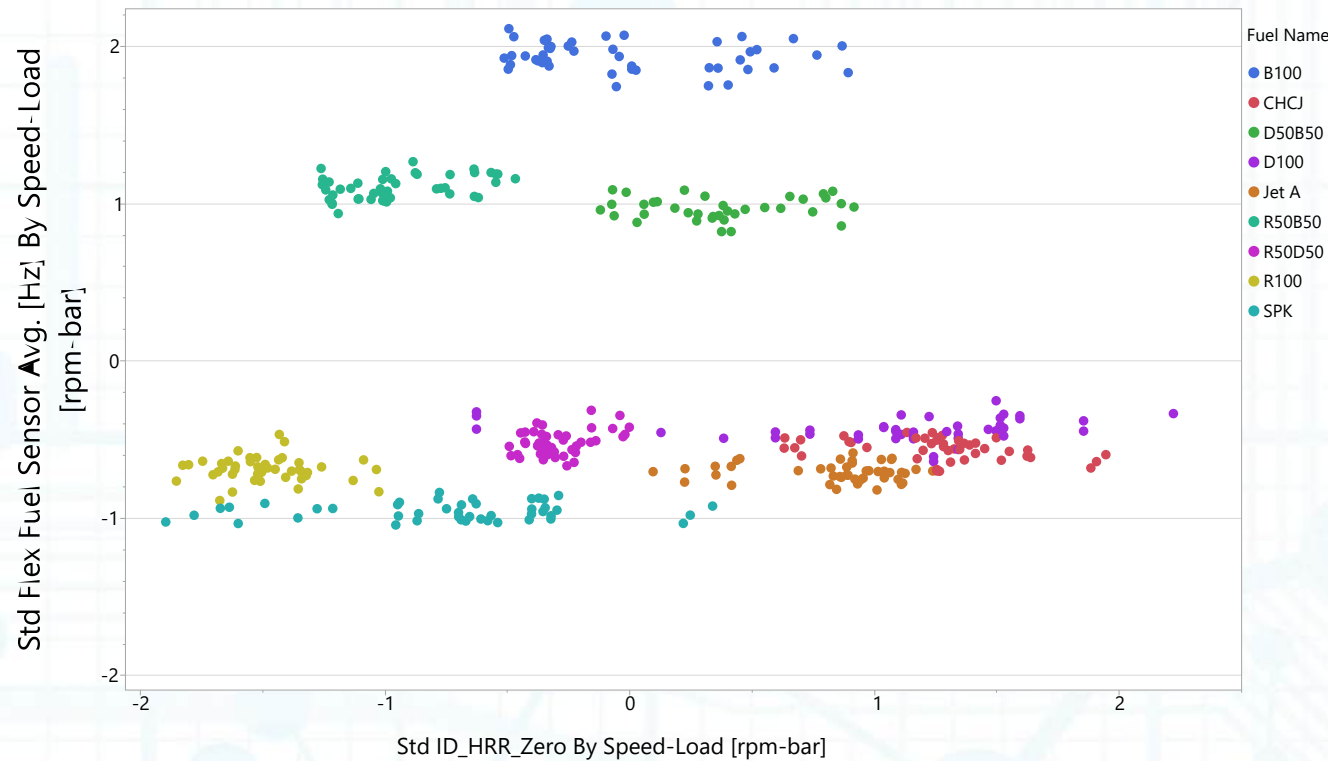


Fuel-SPOT Features: Fuel-SPOT Features: Fuel-SPOT Features: Fuel-SPOT Features:

Fuel Detect	Torque Adapt	Fuel Detect	Torque Adapt
Torque Adapt	DPF Adapt	Torque Adapt	
NO _x Adapt		DPF Adapt	
		NO _x Adapt	

Multiple engine's
responses
demonstrated in
SwRI's Advanced
Engines
Laboratory

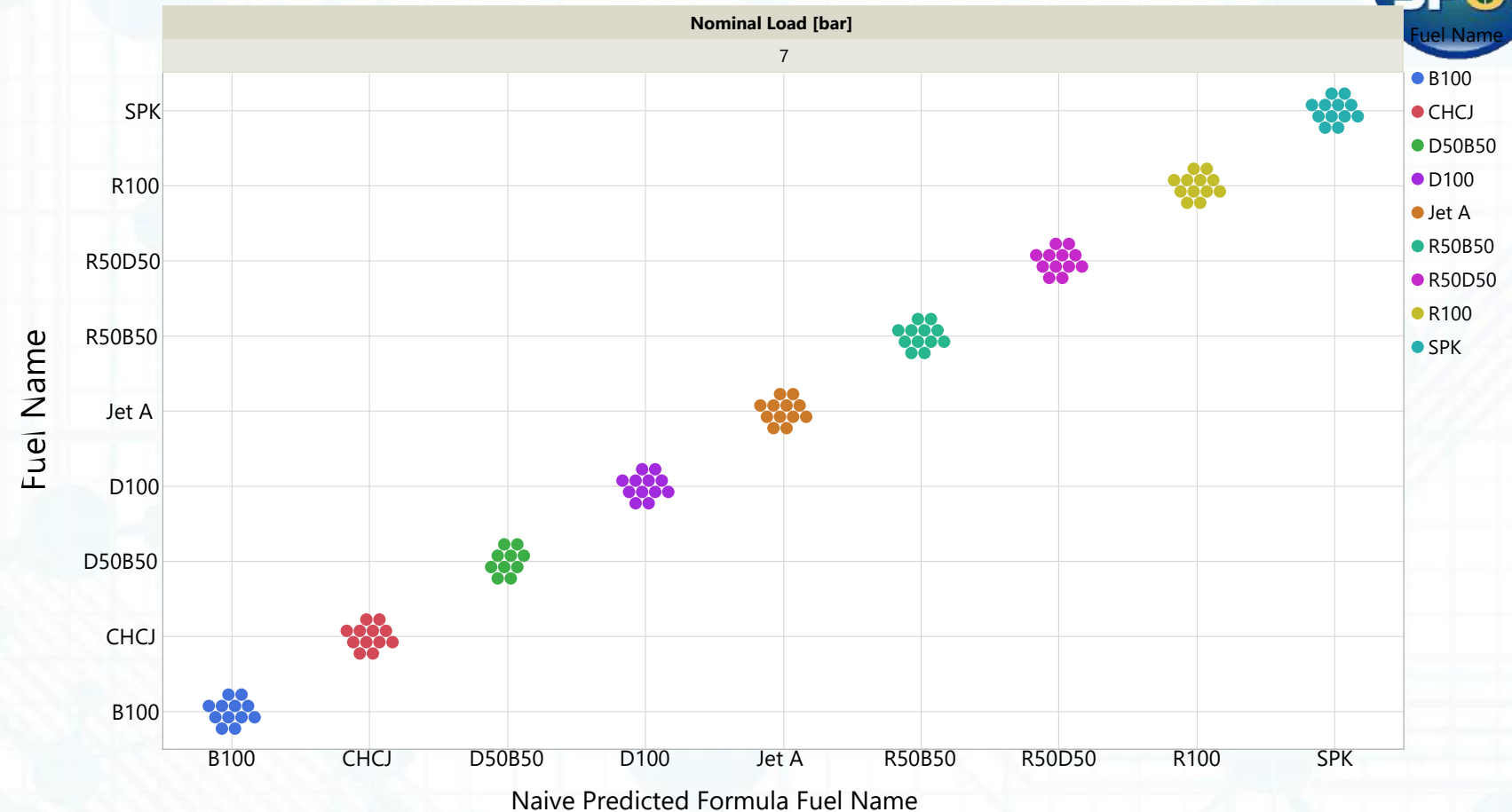
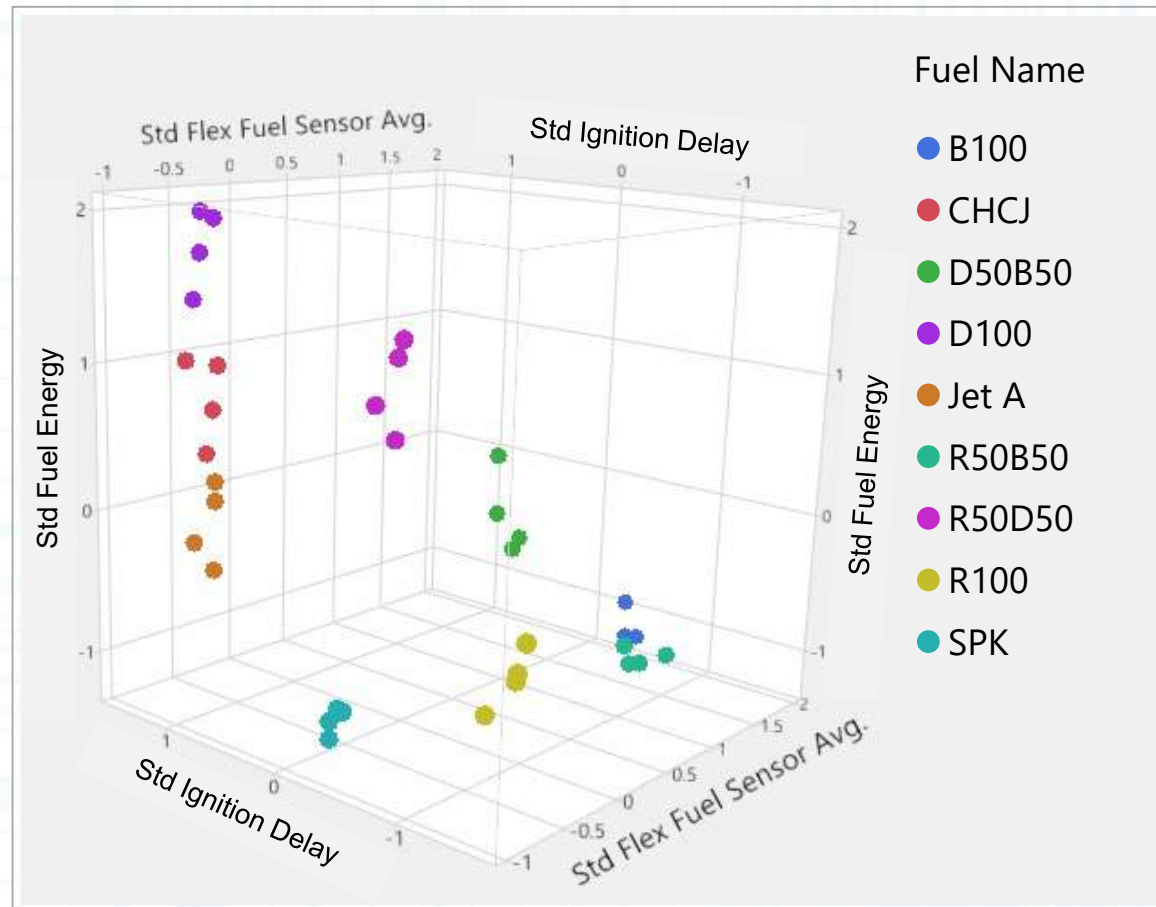
Fuel Sensor and Ignition Location Correlation



- Using all the data from engine mapping, there is excellent separation with little overlap among fuels

- Using support vector machine (SVM) algorithm, boundary lines can be used to express the separation of fuels

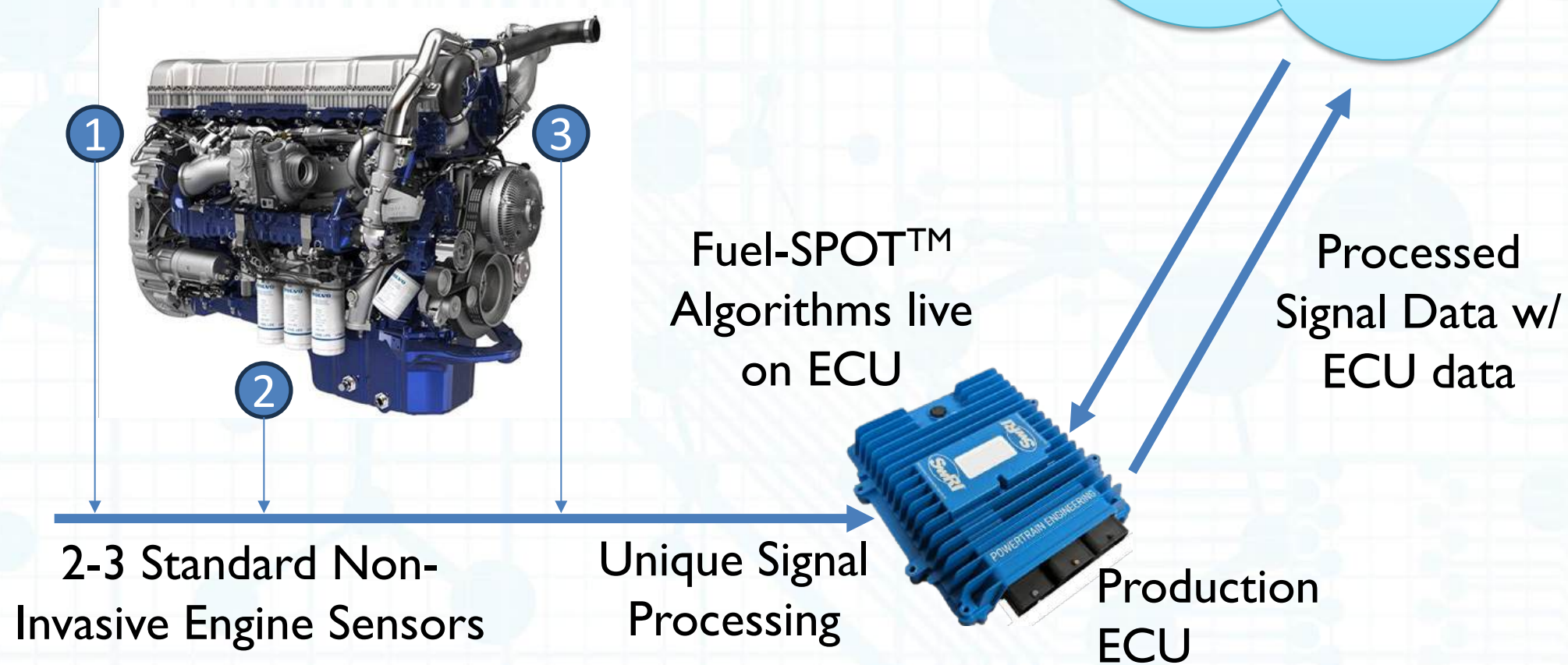
Fuel Diagnostics using the “right” dataset



- Data set or operating conditions can be very critical for the diagnosis of fuels
- We have found several operating conditions that can be useful when the fuel sensor and vibration sensor are used

Fuel-SPOT as part of the Solution

The Fuel-SPOT ecosystem includes the local models on the vehicle but also can aggregate the sensor feedback along with vehicle and region data to the cloud for advanced AI classification and learning

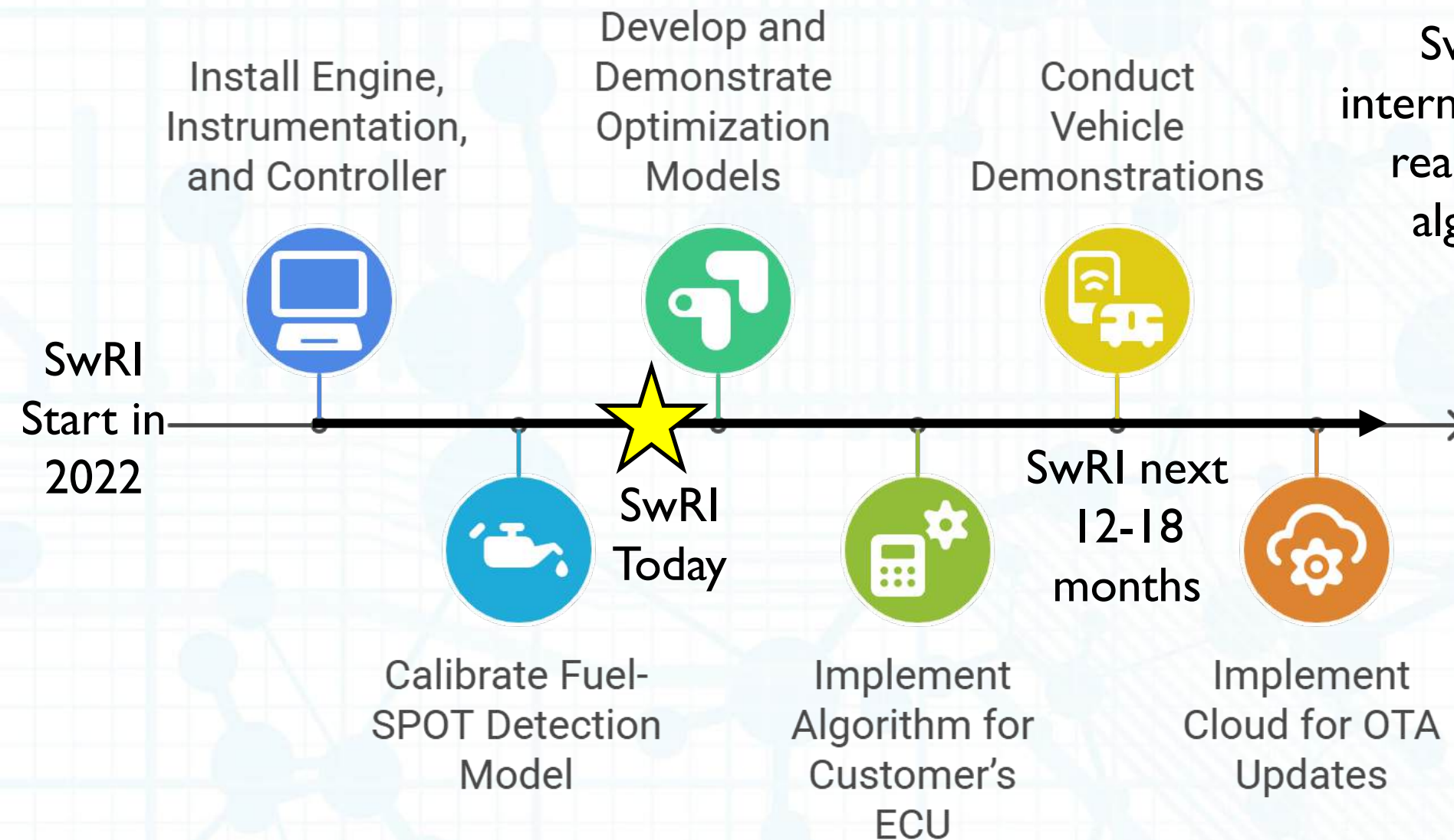




Where is SwRI going with Fuel-SPOT?

SwRI is currently working on an internally funded program to implement real time detection and adjustment algorithms on SwRI's X15 engine

Learn alongside SwRI how fuel blend properties can be detected and optimized in a HD diesel engine



Multiple pieces of IP already filed and more under development



Key Takeaways

Customers want efficiency, range, and the opportunity to use low carbon fuels

- A combination of existing and low-cost sensors can provide flexibility to identify a range of fuels
- Fuel flexibility using technologies like Fuel-SPOT enables customers' opportunistic use of low carbon fuels, and future-proof current powertrains



Fuel-Smart
Performance &
Optimization
Technology

A Project of 

*Benefiting government,
industry and the public
through innovative
science and technology*

Thank you

Imad khalek
Institute Engineer
Commercial Powertrain Systems
+1-210-522-2536
Imad.Khalek@swri.org



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