Utilizing data-based modeling with low life cycle GHG emissions algae biofuels for engine optimization

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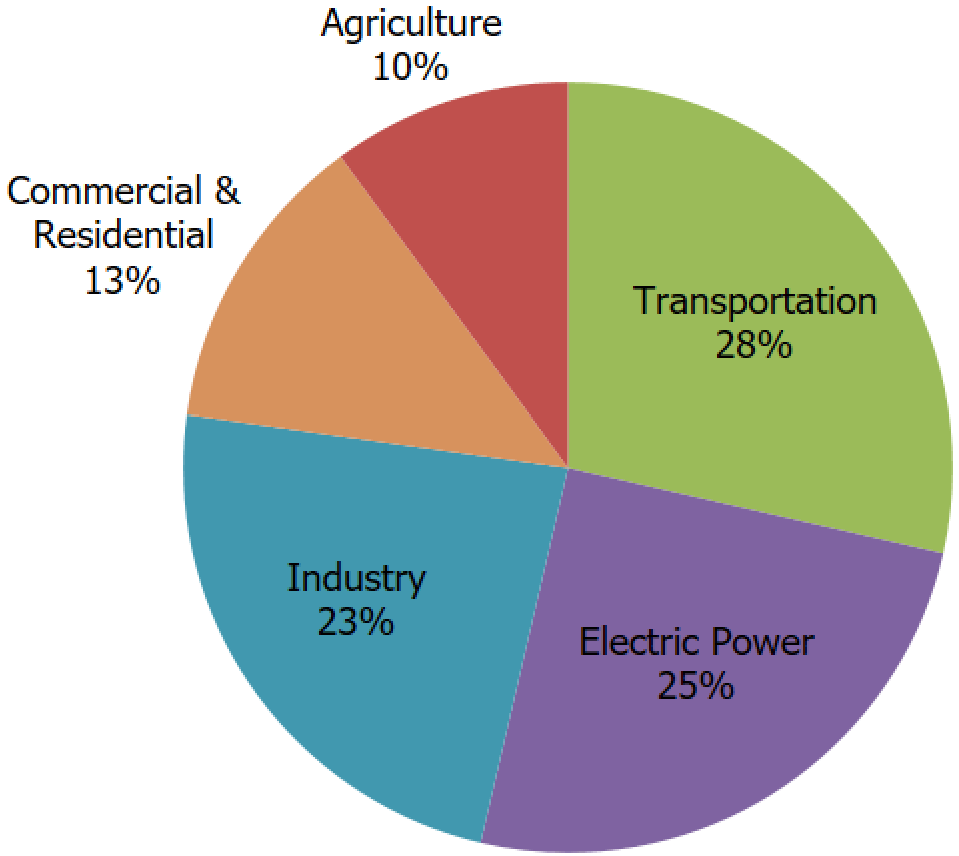
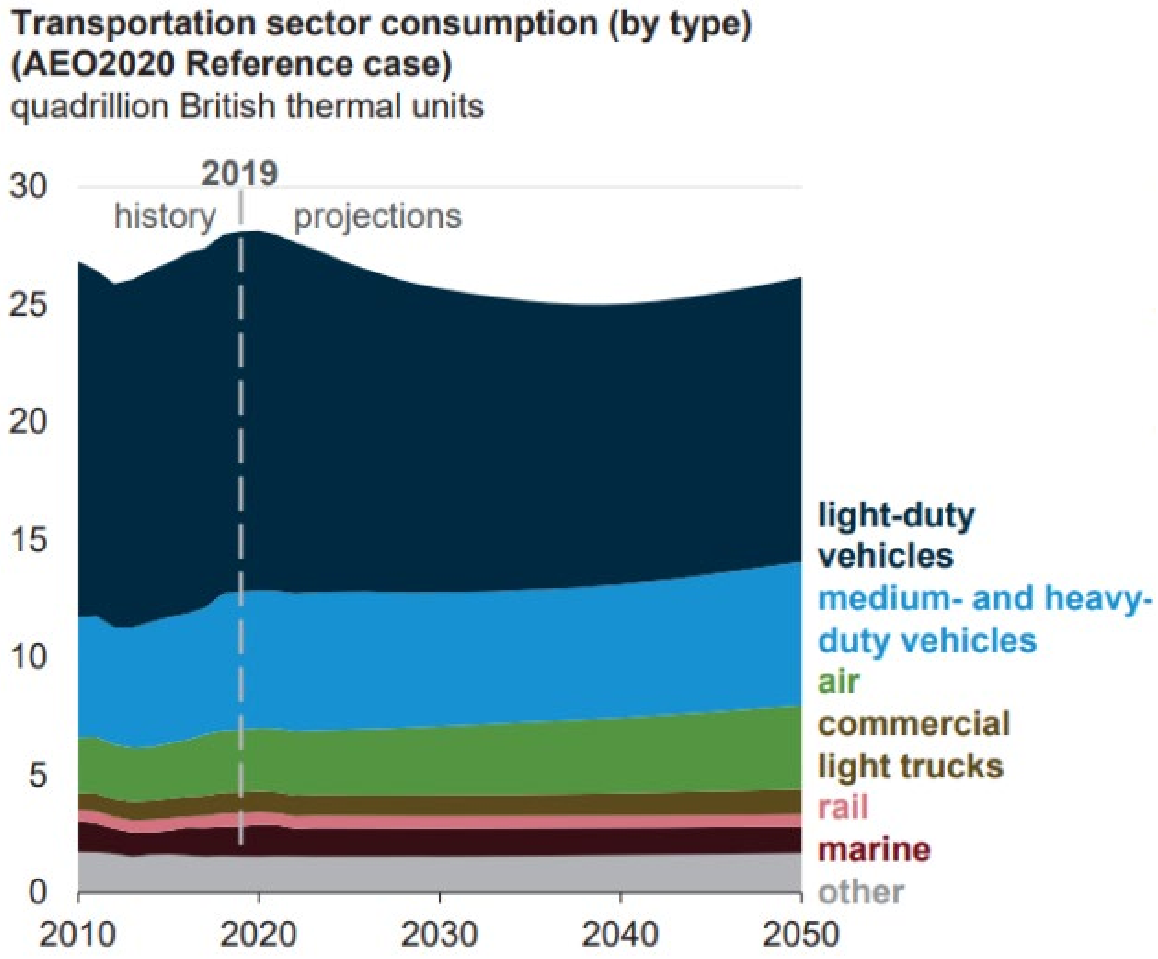
Background and motivation

Total U.S. 2021 Emissions by economic sector





EPA (2023)

Challenges and potential solutions

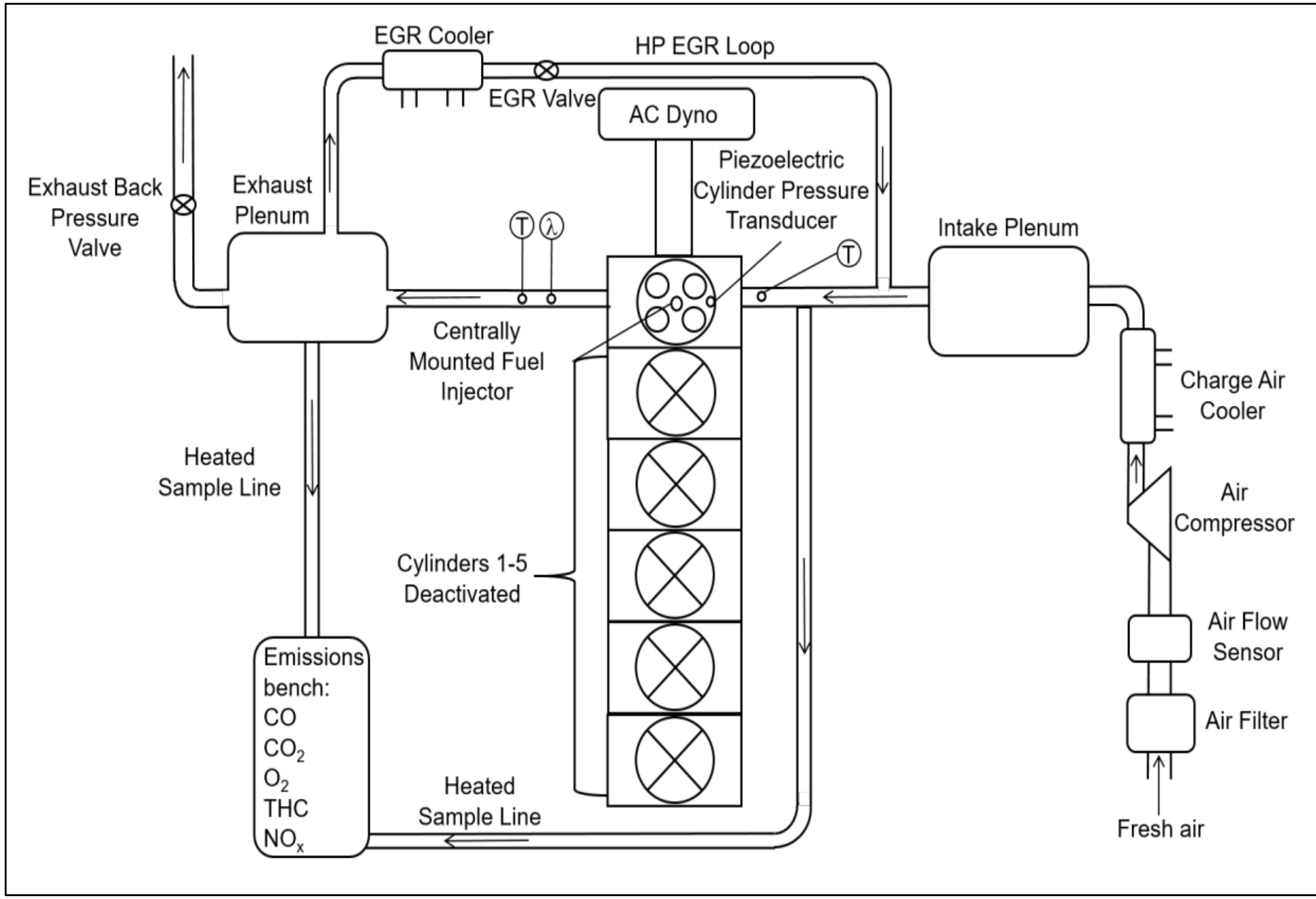
- Today's Heavy Duty engines convert only 46% of the fuel energy consumed (Amar et al., 2020)
- Minimize losses contributing towards decrease fuel conversion efficiency, and
- Focus on increasing fuel conversion efficiency.
- Interest grows in biofuels as a supplementary alternative – Fatty Acid Methyl Esters (FAME), Hydrogenated Vegetable oils (HVO) [Hoekman et al., 2011]

Research Study Objectives

- Tailored bioblendstocks with low environmental impact to optimize MCCI engines.
  - Engine Optimization
  - Study of fuel's impact on efficiency and GHG emissions

Experimental Setup

- A modified 11L Volvo MD11 heavy duty engine
- Deactivated cylinders 1-5



Garcia, E (2021)

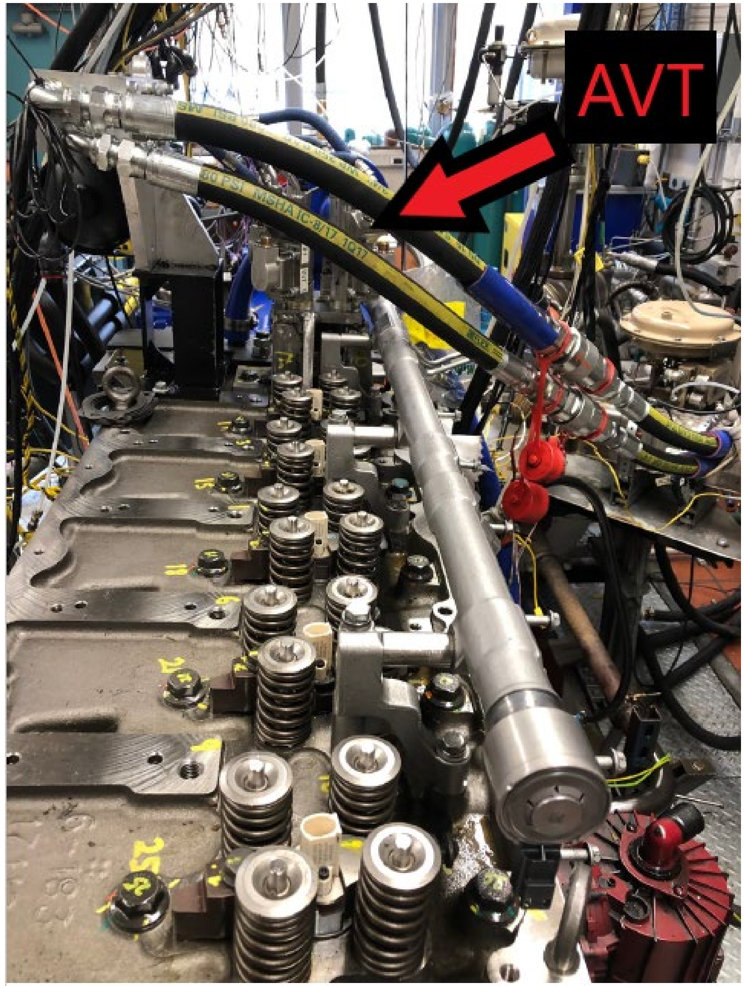
Experimental Setup

Conventional Camshaft

←

Lotus AVT setup

→



Operating Conditions – A50

- Control Parameters:
- Intake Air Pressure, Injection Rail Pressure, Start of Injection, Relative Pilot Injection, EGR
- Operating Speed = 1160 rpm
- Targeted load = 11.9 bar
- 3 fuels:

1) Marathon Baseline Diesel (MB),
2) 30% n-Hexadecane blended Diesel (A30),
3) 100% Hydrogenated Vegetable Oil/Renewable Diesel (RD)

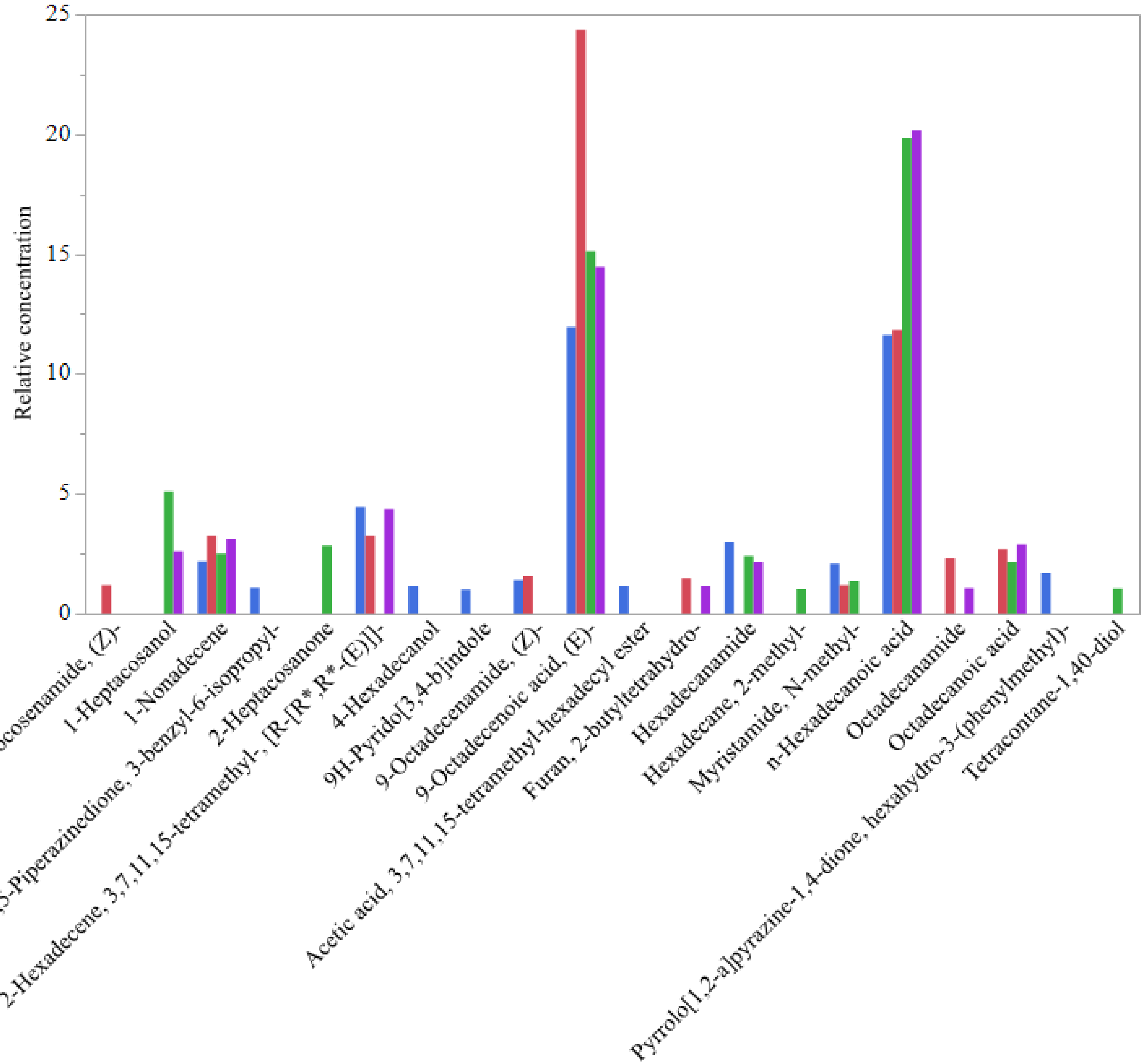
Fuel Properties

Fuel Property	Unit	Ultra-Low Sulphur Diesel	A30 (30% n-C16 blended diesel)	100% Renewable Diesel
Short name	-	MBase	A30	RD
Derived cetane number	[-]	48	62	75
Lower heating value	MJ / kg	43.1	43.3	44.1
Density	g / L	835	820	784
Viscosity	mm^2/s	2.29	2.64	2-4
Flash point	°C	67	73	89

Experimental Setup

Parameter	Value
Test engine	Volvo MD11
Number of cylinders	1 (5 deactivated)
Displaced volume	1.81 L
Bore x stroke	123 mm x 152 mm
Connecting rod length	225mm
Geometric compression ratio	16.74:1 (Ch.3 and Ch5); 19:1 (Ch. 4)
Cylinder head	4 valves, fully-variable valve timing
Diesel injection system	Common rail
Injector	6 hole nozzle
Piston design	Wave bowl
EGR system	High pressure loop

GC-MS Analysis of hydrothermally treated upgraded algae biofuel



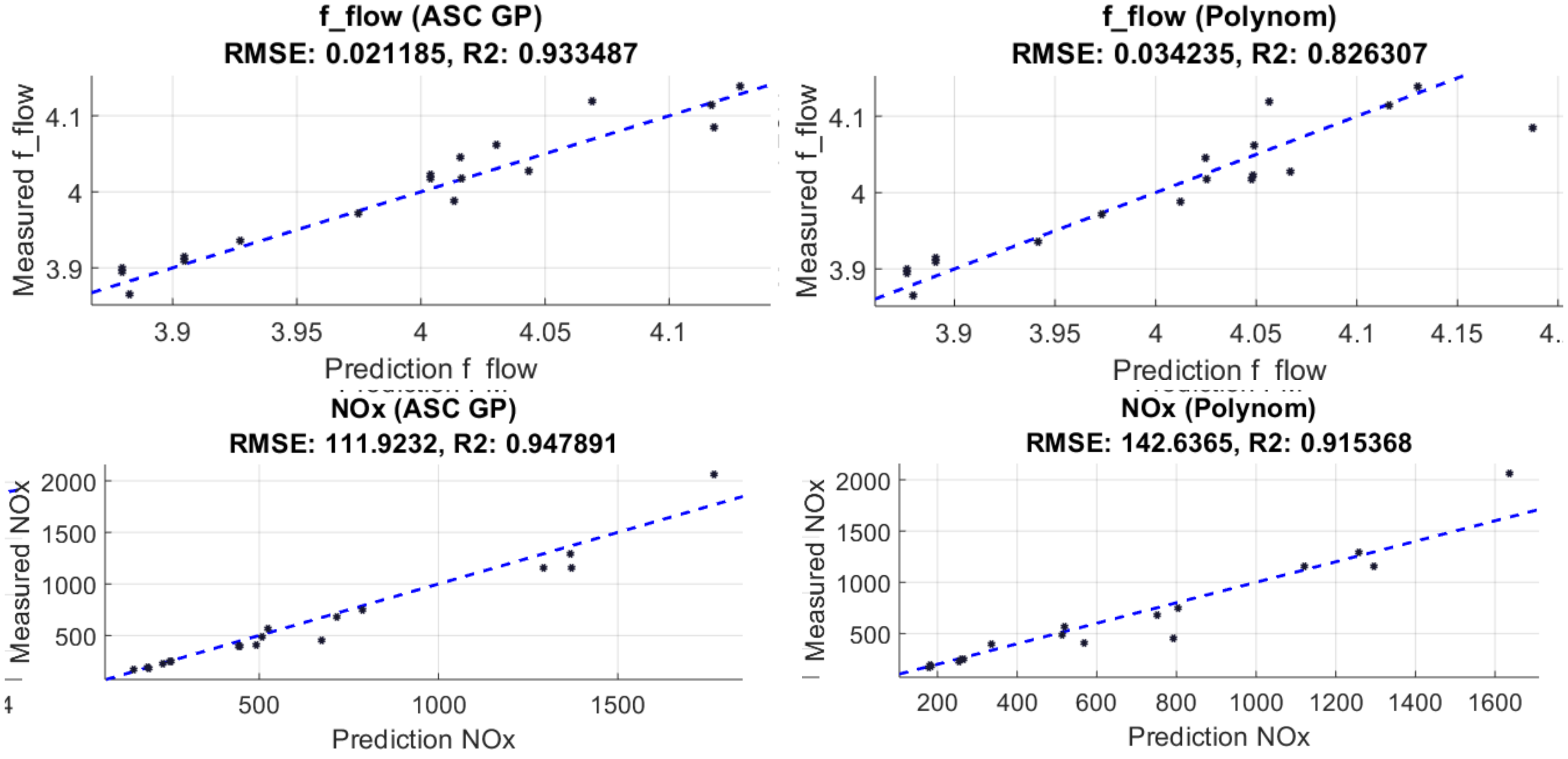
Data Driven Optimization

ETAS ASCMO

- Advanced Simulation for Calibration, Modeling and Optimization
    - Modeling Input/output behavior
- Industrial grade DOE and optimization
- Space-filled method vs sweep method
    - 64 test points vs over 1500 test points using sweep methodology

Model quality – RMSE

- Significantly better model prediction for fuel flow and NOx for Gaussian process vs polynomial fit



Model quality – RMSE – Continued …

- Model fails to capture total hydrocarbon behavior.
- $0 < R^2 < 0.5$

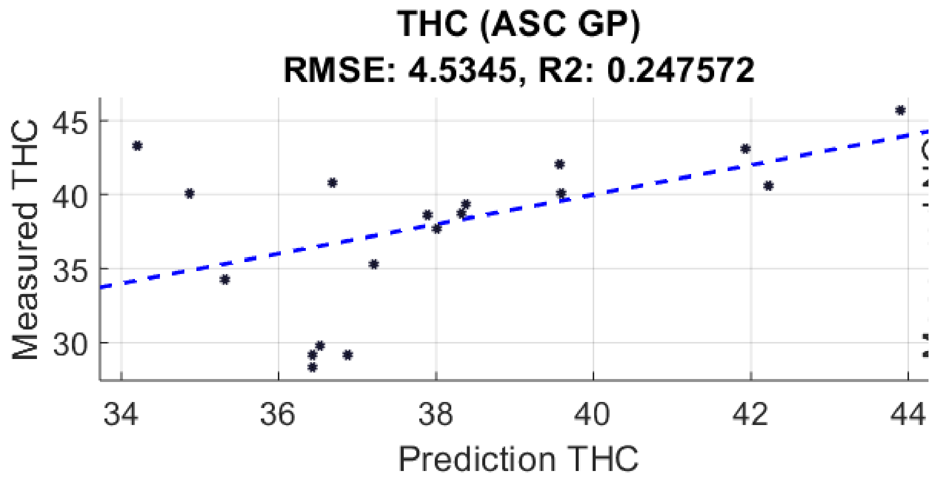
The model is not suitable for reliable predictions

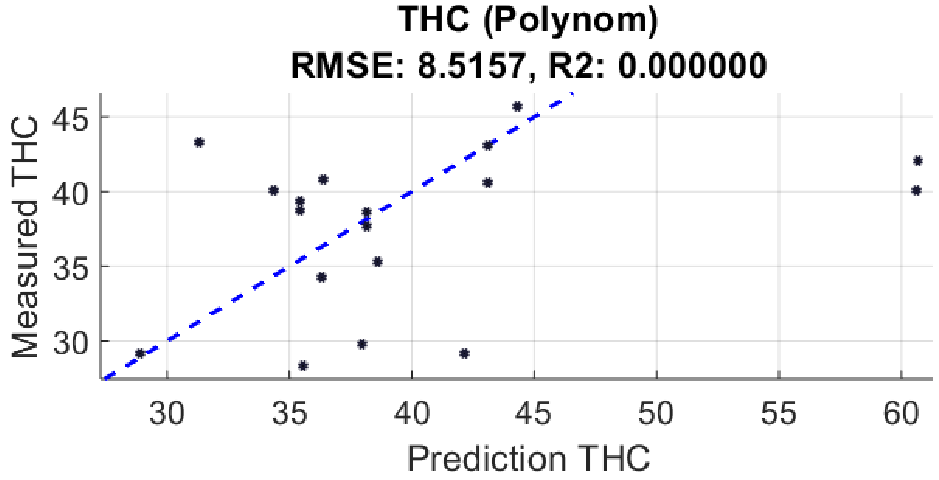
- $0.6 < R^2 < 0.8$

The model is suitable for qualitative predictions.

- $0.9 < R^2 < 1$

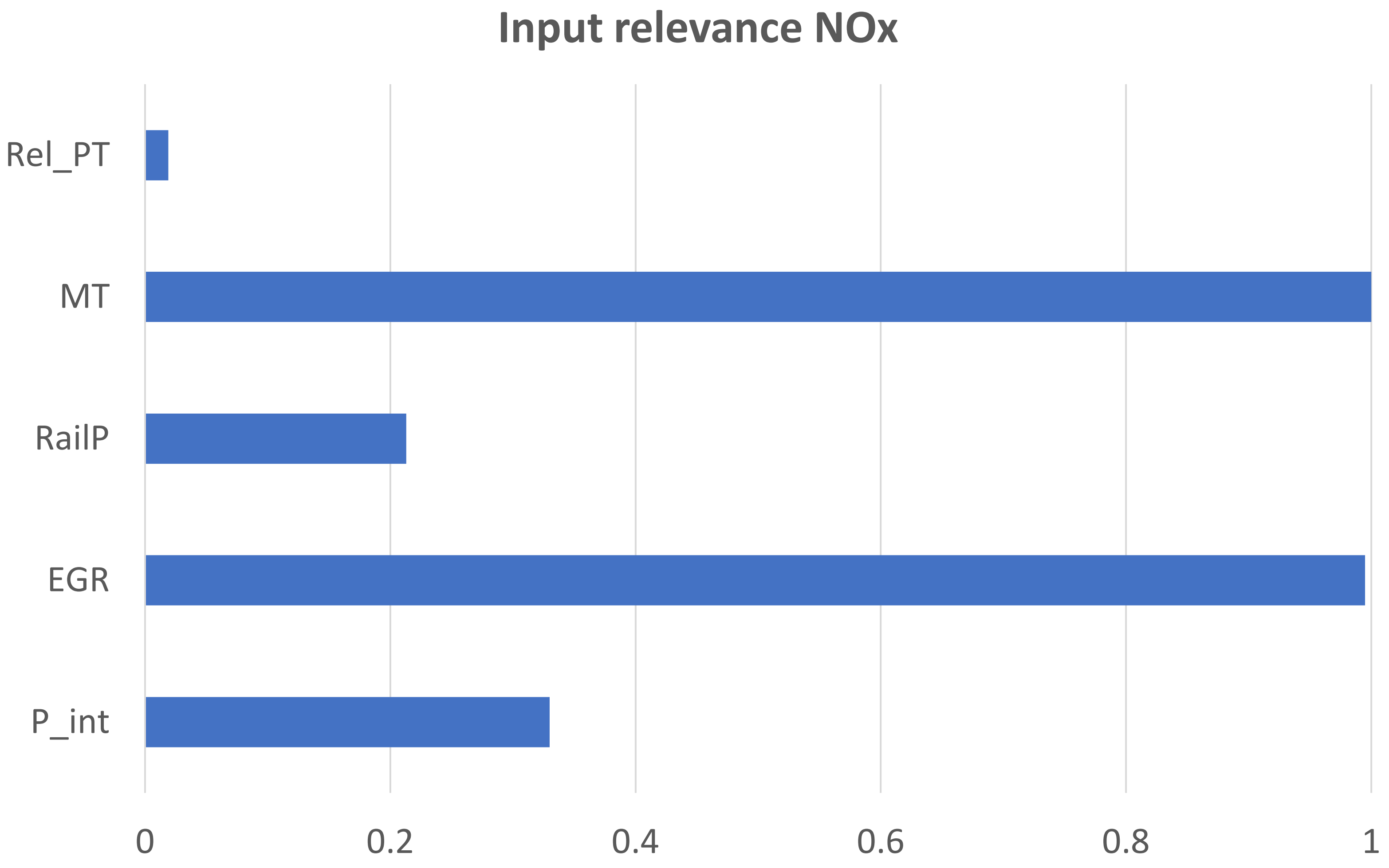
The model is very good and therefore suitable for quantitative predictions.





NOx relevance modelling

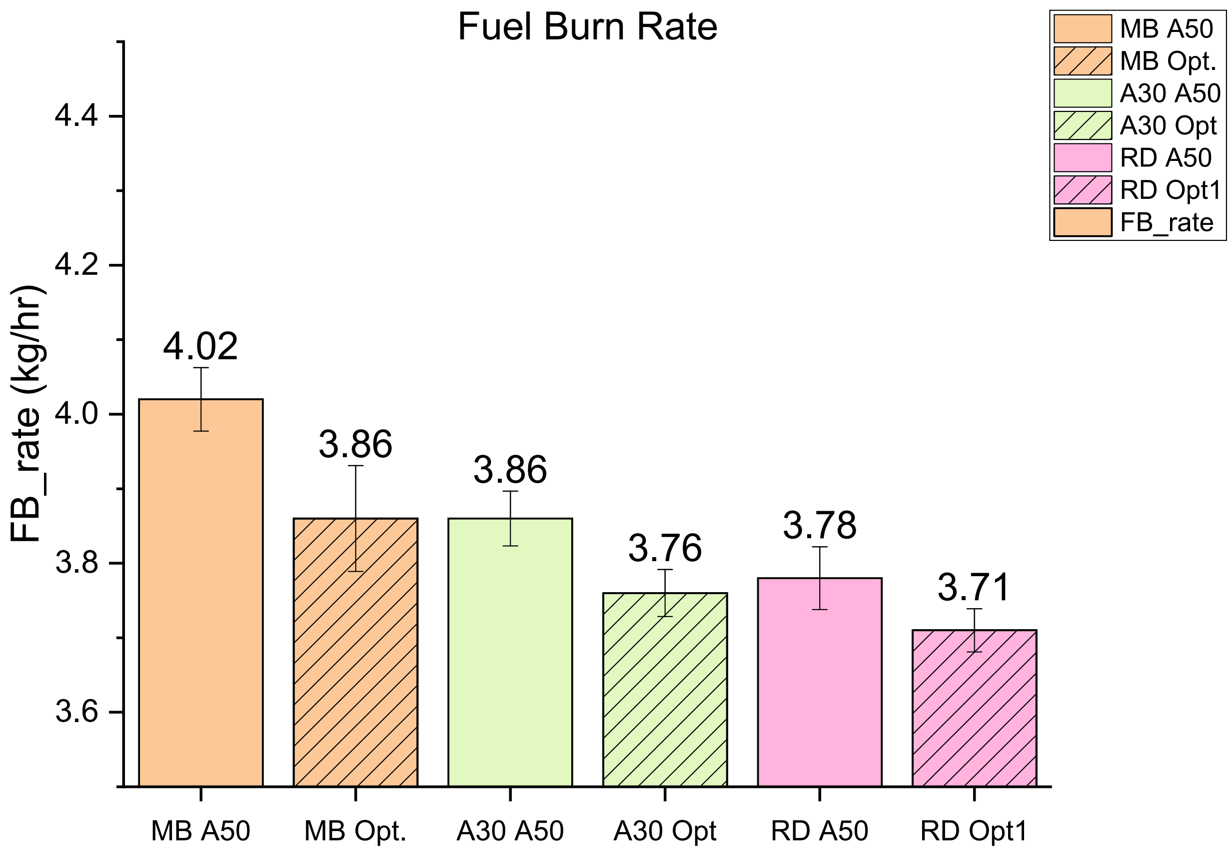
- The input/output relevance for NOx emissions indicating a strong dependence on Start of Injection and EGR
- SOI impacts combustion -> impacts NOx emissions



Results

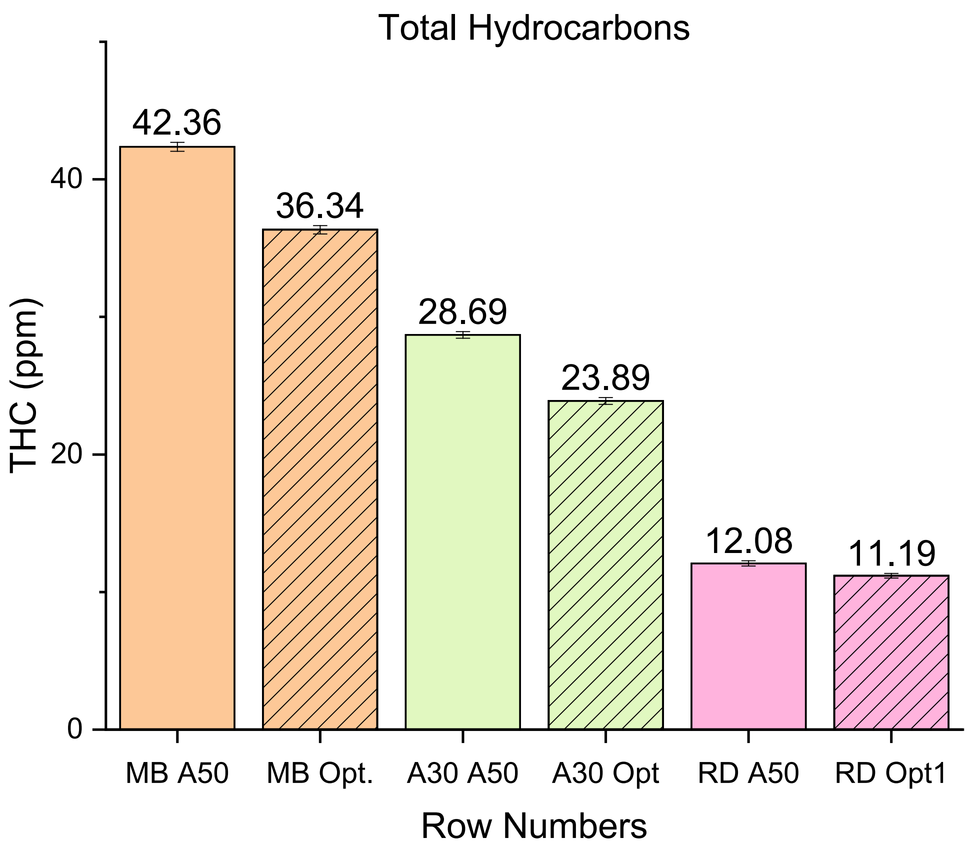
Summarized results – Fuel burn rate

- Approx. 7.7% fuel consumption reduction utilizing renewable diesel and optimization approach.
- RD offered the least room for reduction.
- Optimized diesel vs. baseline A30; optimized A30 vs. baseline RD.



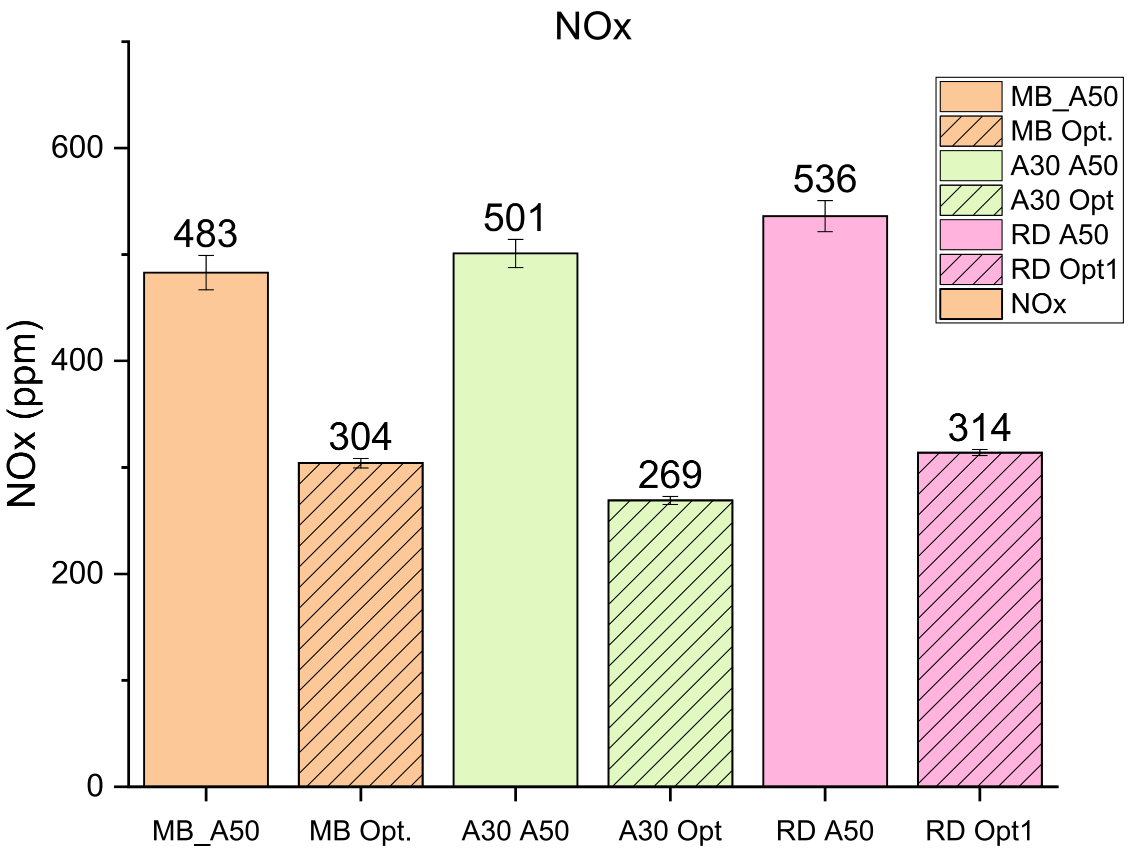
Summarized results – Total Hydrocarbons (as C1)

- A gradual decrease in THC emissions reaching maximum of 73% reduction.
- Insignificant improvement for Renewable Diesel



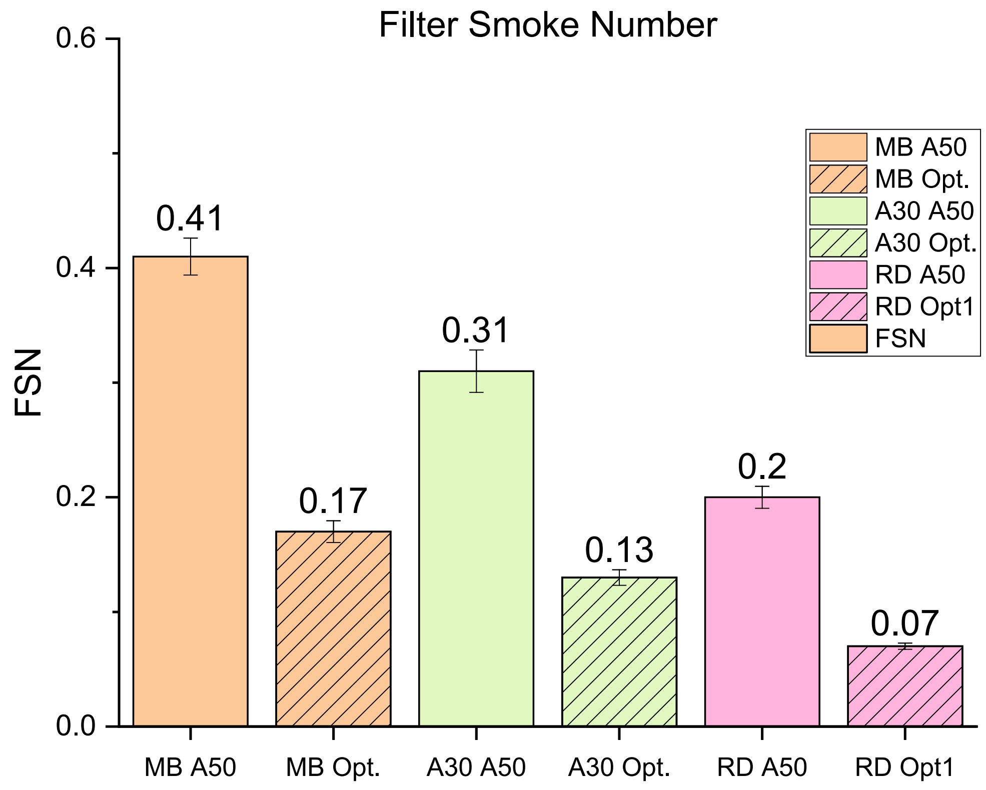
Summarized results – NOx emissions

- Increasing biofuel content shows an increase in NOx emissions for baseline operating conditions.
- NOx mitigation through EGR



Summarized results – Filter Smoke Number

- Reverse trends as compared to NOx emissions.
- RD offered the maximum benefit in FSN reduction



Learning outcomes

- Use of straight chain Hydrocarbons instead of oxygenated compounds through upgradation
  - Higher BTE and lower GHG emissions
  - Higher DCN
- Reduced BSFC which eventually leads to reduced overall Carbon emissions
- Reduced NOx emissions
- Reduced soot emissions at optimized points
- (further to investigate) overall Life cycle GHG emissions, chemical kinetics study of n-Hexadecane for fuel behavior study

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Suggestions/Recommendations