Emission Solutions

Impact of biodiesel on after treatment catalysts

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Cummins Emissions Solutions

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Public

Acknowledgement

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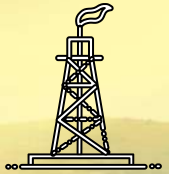
Outline

- Role of Alternate Fuel in Destination Zero
- Biodiesel
- Fuel properties & Fuel Standards
- Impact on Engine out Emissions
- After-treatment Selection
- Impact of emissions on catalyst
- Summary

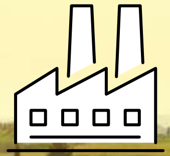
Decarbonizing the total chain of emissions is essential

WELL-TO-WHEELS EMISSIONS



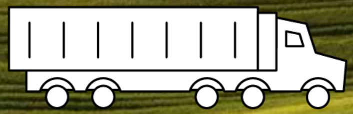
Removing coal, oil, natural gas or raw materials from the earth

Transportation and distribution →



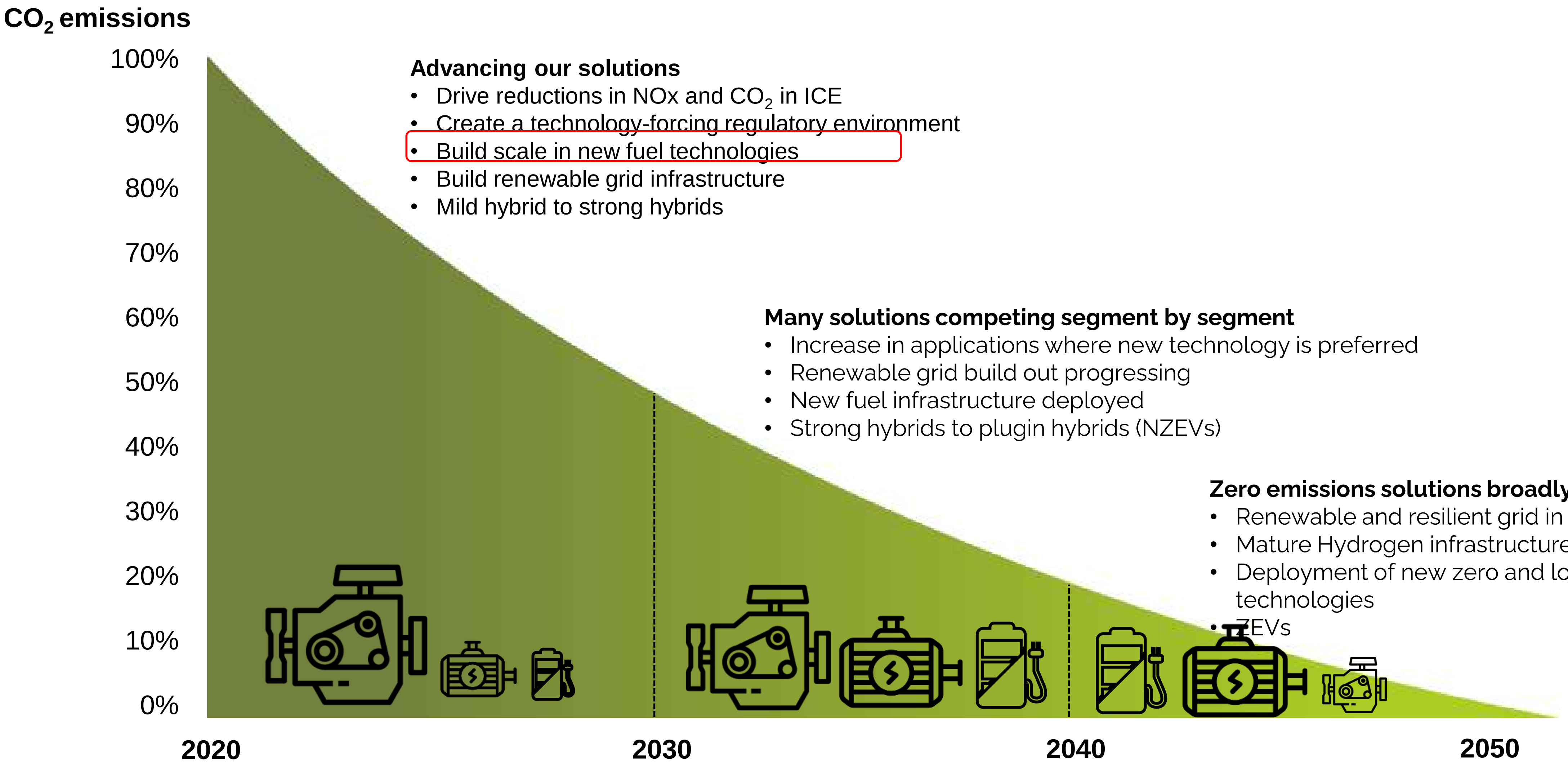
Refining or processing into a usable power source

Transportation and distribution →



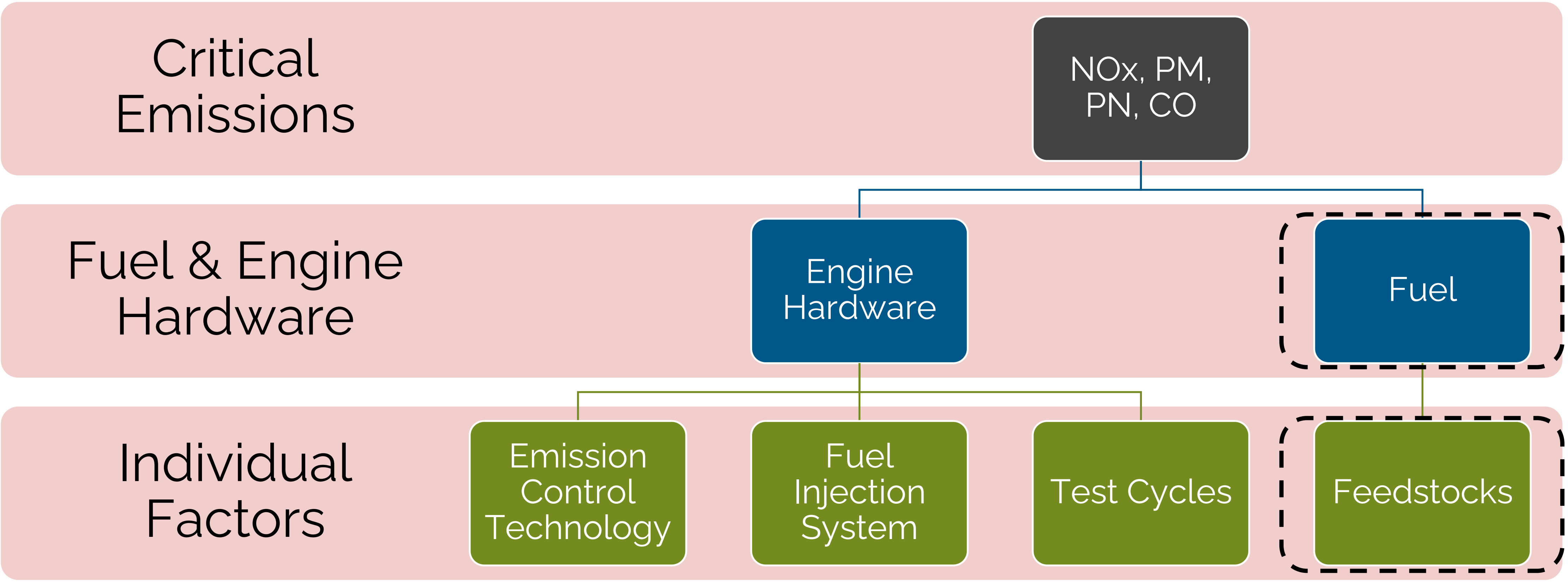
In-use emissions

Reaching Destination Zero



Driving factors: *energy source decarbonization and infrastructure investment, regulatory advancements, and customer pull*

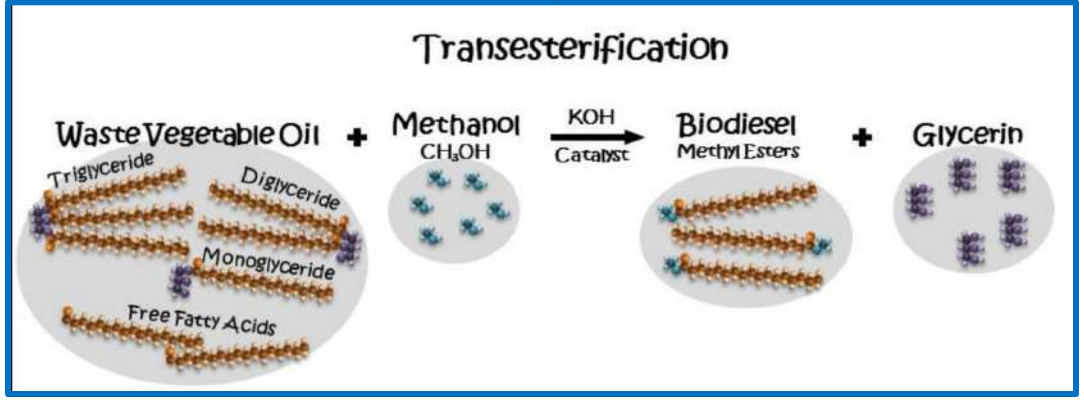
Impact of Biodiesel on Engine Emissions



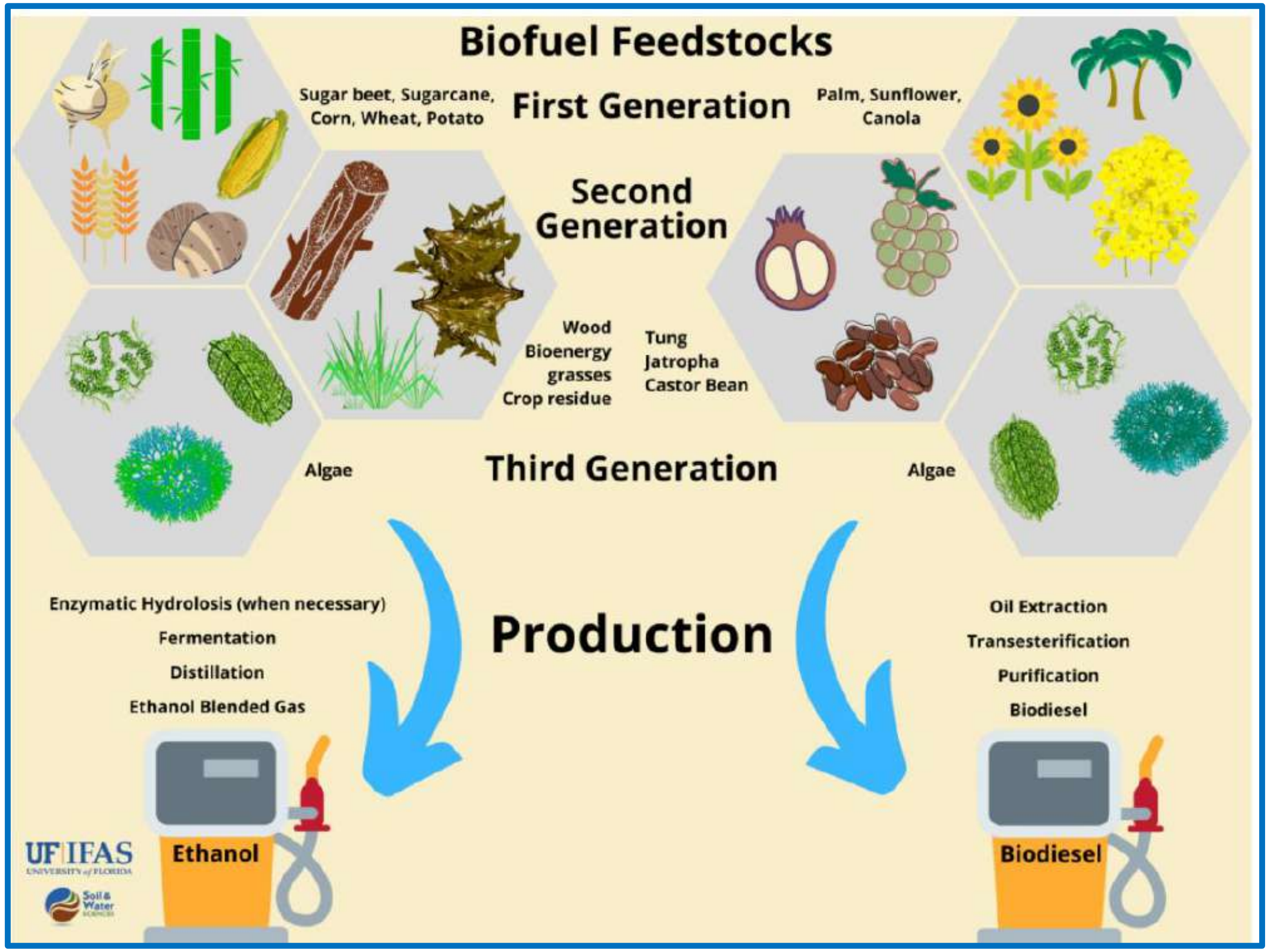
Fuel Source: Why Biodiesel?

Key Features of the Fuel

- Sources: Vegetable oils or Animal fats
- Process: Transesterification
- Eliminates CO2 and Oxides of Sulfur
- Used in diesel engines with minor or no modifications
- Biodegradability



Courtesy: Biodiesel – Archived – Engineers for a Sustainable World UBC



Courtesy: Get to know biofuels - Soil, Water, and Ecosystem Sciences (ufl.edu)

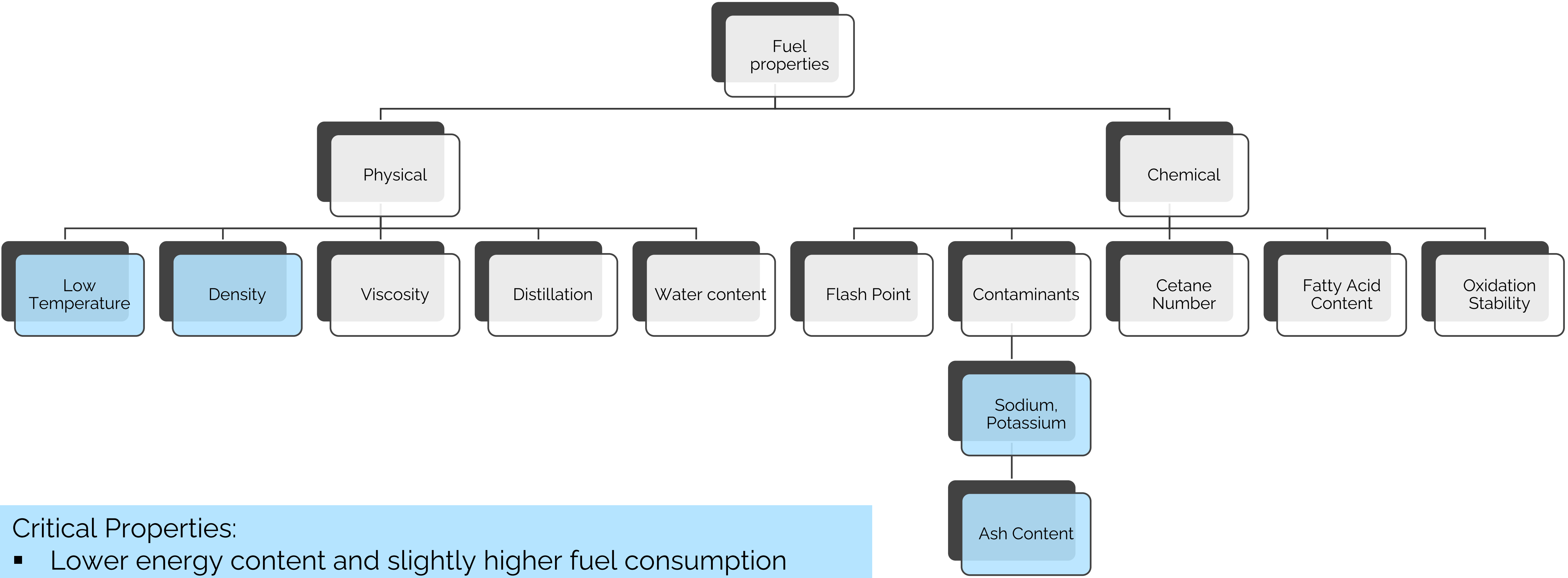
Global Biodiesel Specifications

- Automotive diesel fuel in Europe is EN590:
  - EN590 – Automotive fuels. Diesel.
    - Includes up to 7% (B7)
- Up to B100 :
  - EN14214 – Up to B100
- Blends:
  - EN16709 – Up to (B20 and B30)
  - EN16734 – Automotive fuels – Automotive B10 diesel fuel – Requirements and test methods

- Automotive diesel fuel in North America is ASTM D975:
  - ASTM D975 – Standard Specification for Diesel Fuel
- Upto B100:
  - ASTM D6751 - Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels
- Blends:
  - ASTM D7467 - Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20)

- Automotive diesel fuel in India is BIS:
  - IS 1460– Standard Specification for Diesel Fuel
- Upto B100:
  - IS 15607- Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels
- Blends:
  - IS 15607- Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20)

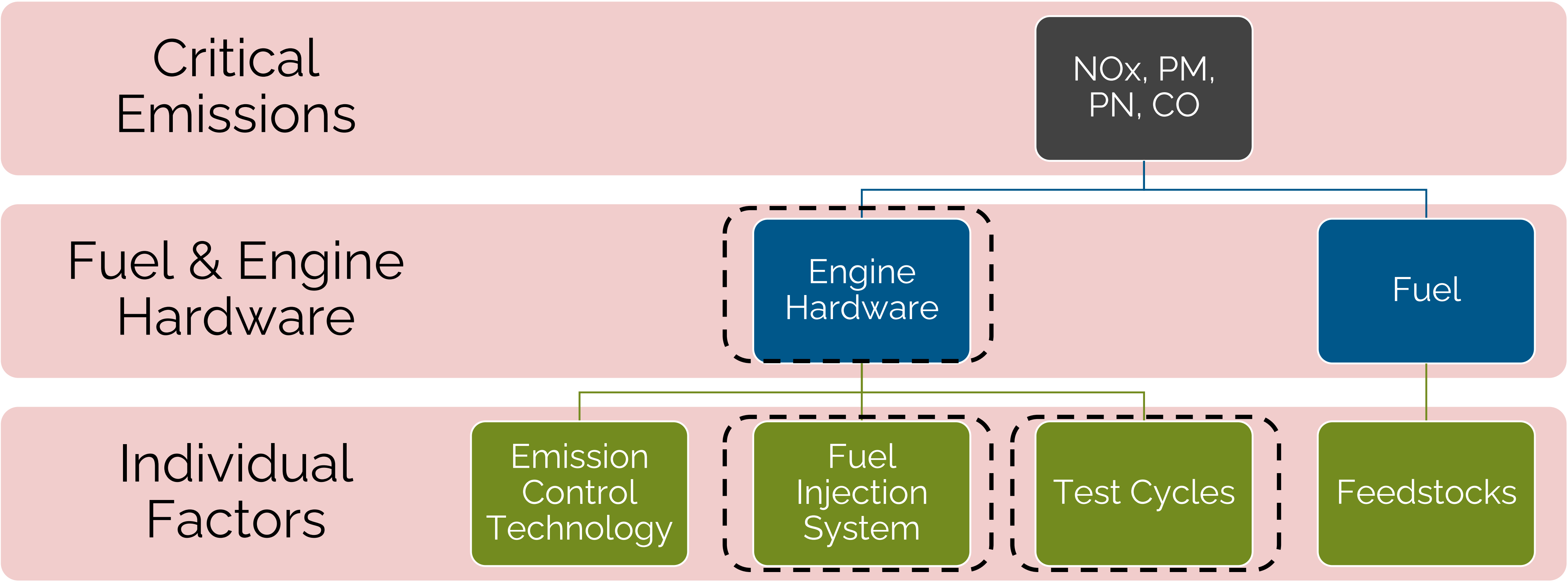
Biodiesel Fuel properties



Critical Properties:

- Lower energy content and slightly higher fuel consumption
- Needs Improvement in Low Temperature properties
- Low volatility impacts the ATS catalyst performance
- Potassium and Sodium impacting the after-treatment system

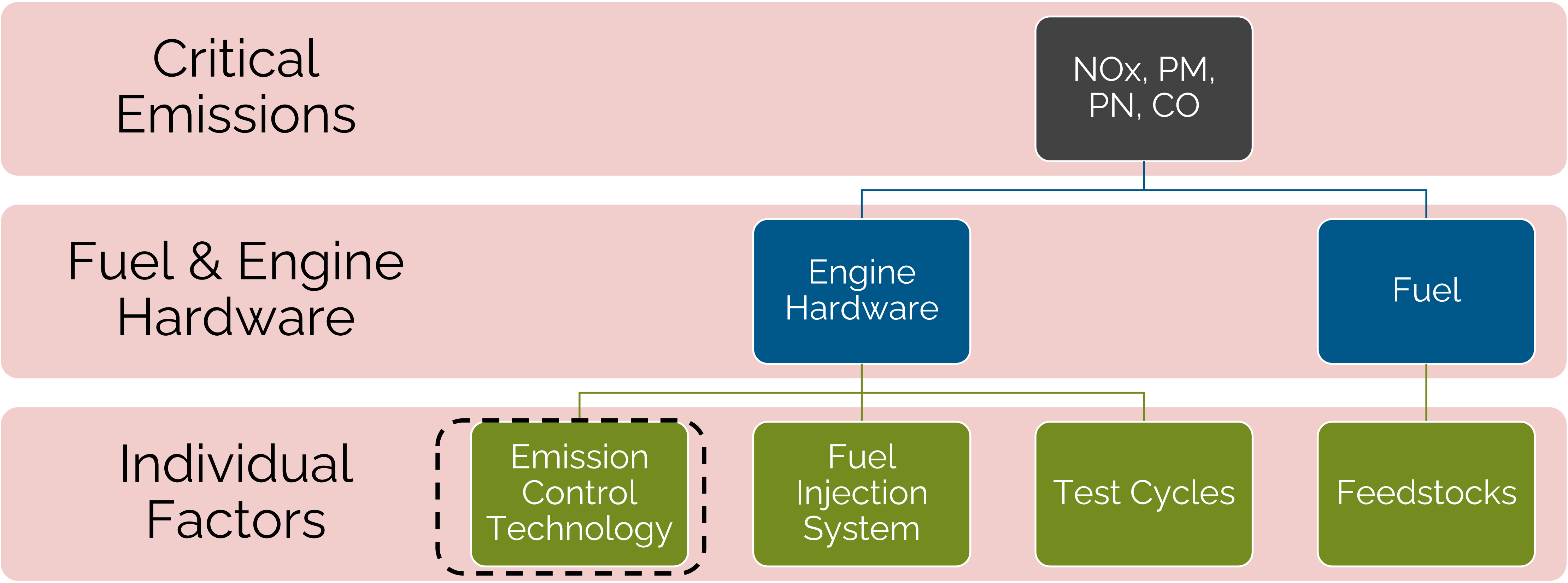
Impact of Biodiesel on Engine Emissions



Literature review on Engine emissions

Study	Engine	Test Cycle	Blend Level	NOx	CO	HC	PM	PN	Comments
Lapuerta et al (2008)	Various	Various	Various	↑	↓	↓	↓	No Clear Trend	
Fontaras et al (2009)	Euro II Diesel Passenger Car (1.9L Engine)	NEDC & Artemis	B100	↑	↑	↑	↑	↑	Included a DOC in architecture – measured tailpipe emissions
Jedynska et al (2015)	DAF XE355 6-cyl 12L 355kW	ETC	Multiple inc. B100	↑	↓	No Change	↓	↓	
Cheikh et al (2016)	Naturally aspirated, direct injection, 7.5kW, single cylinder 0.6L	Steady State Maps	Multiple inc. B100	↑	↓	↓	↓	Not Reported	
Nyström et al (2016)	4 cyl, 4L, 74.6kW Stage I/Tier 1 engine (mechanical distributor pump, direct injection)	Urban Part of ETC	RME B100 & B30 with ACP additive	↑	↓	Not Reported	↓	↓	
Tomić M et al (2021)	4V-CR 6-cyl 6.8L engine – Stage II installed in a Farm Tractor	Steady State Map	B40	↑	↓	Not Reported	Not reported	Not Reported	
O'Malley & Searle (2021) All Data	Various (Meta-Analysis)	Various (Meta-Analysis)	Various (Meta-Analysis)	↑	No Change	↓	↓	Not Reported	Study based on tailpipe emissions as opposed to engine out – some data points will include aftertreatment systems
O'Malley & Searle (2021) "Modern Conditions"	Various (Meta-Analysis)	Various (Meta-Analysis)	Various (Meta-Analysis)	↑	↑	↑	No Change	Not Reported	

Impact of Biodiesel on Engine Emissions



Catalysts in BSVI architecture

Diesel Oxidation Catalyst (DOC)

Used to oxidize the Hydrocarbons, Carbon Monoxide, & Provide Regen Temperatures

Diesel Particulate (DPF) Filter

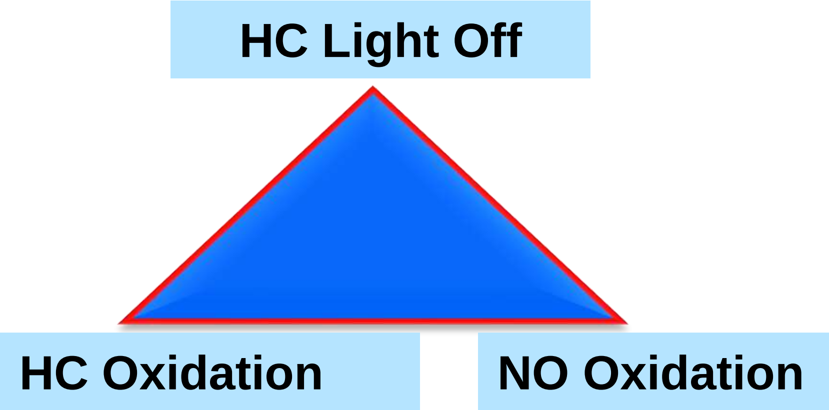
Uses wall-flow substrates to remove particulate matter & reduce particle number

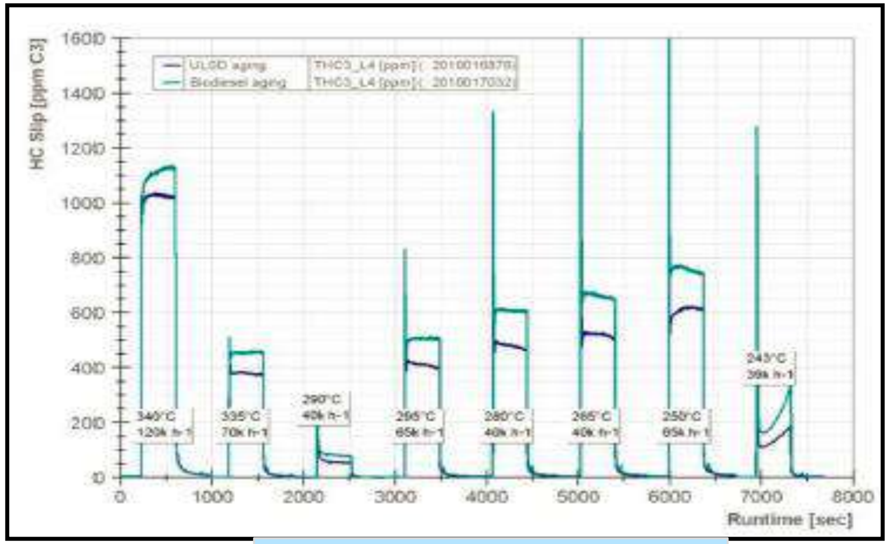
Selective Catalytic Reduction (SCR) System & Ammonia Slip Catalyst (ASC)

Reduces oxides of nitrogen emission and reduces ammonia slip

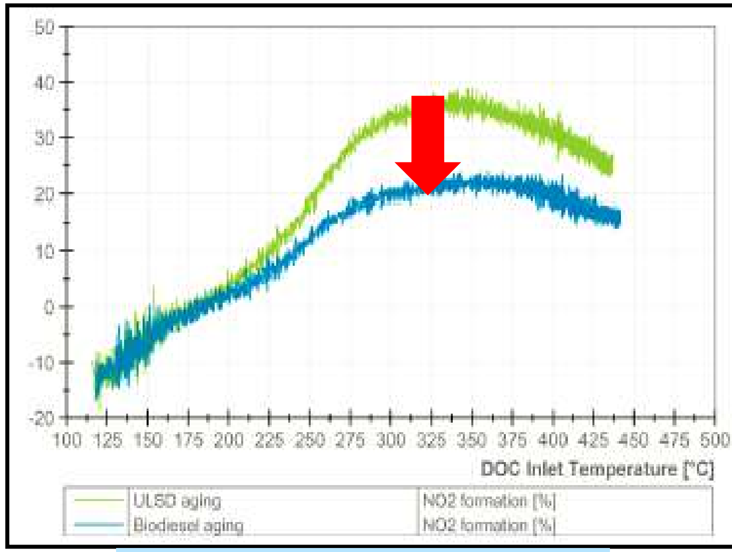
Impact on DOC

Reference: Different Properties of Biodiesel in Comparison with Standard Diesel Fuel and their Impact on EURO VI Exhaust Aftertreatment Systems, Kattwinkel et al (2012)
Impact of Biodiesel Impurities on the Performance and Durability of DOC, DPF and SCR Technologies, Williams et al (2011)



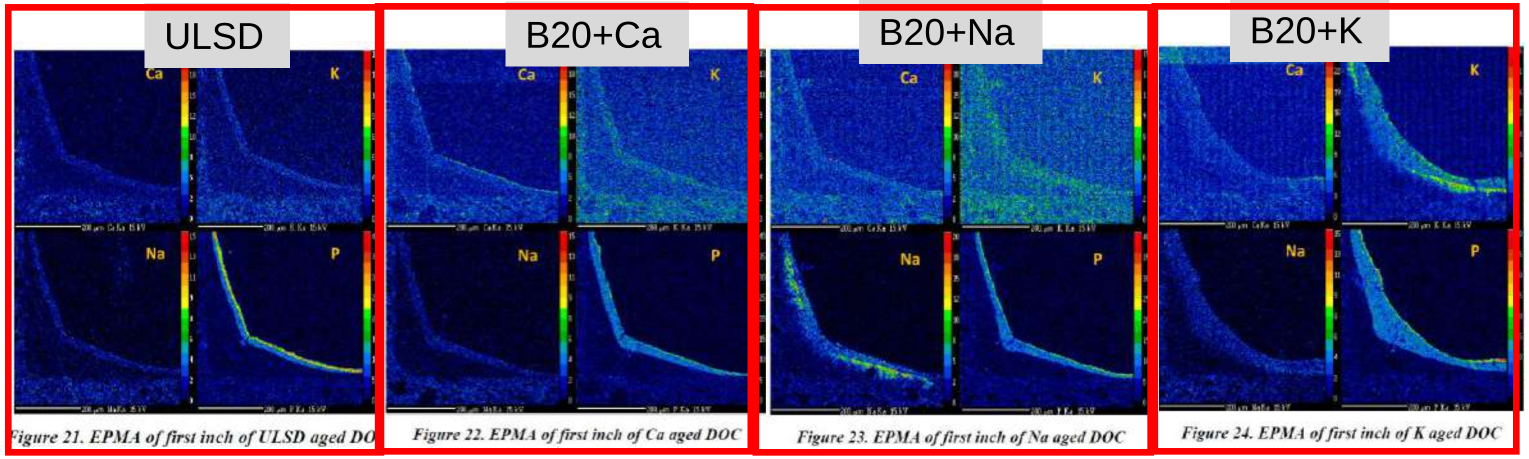


HC conversion decrease



NO2 formation decrease

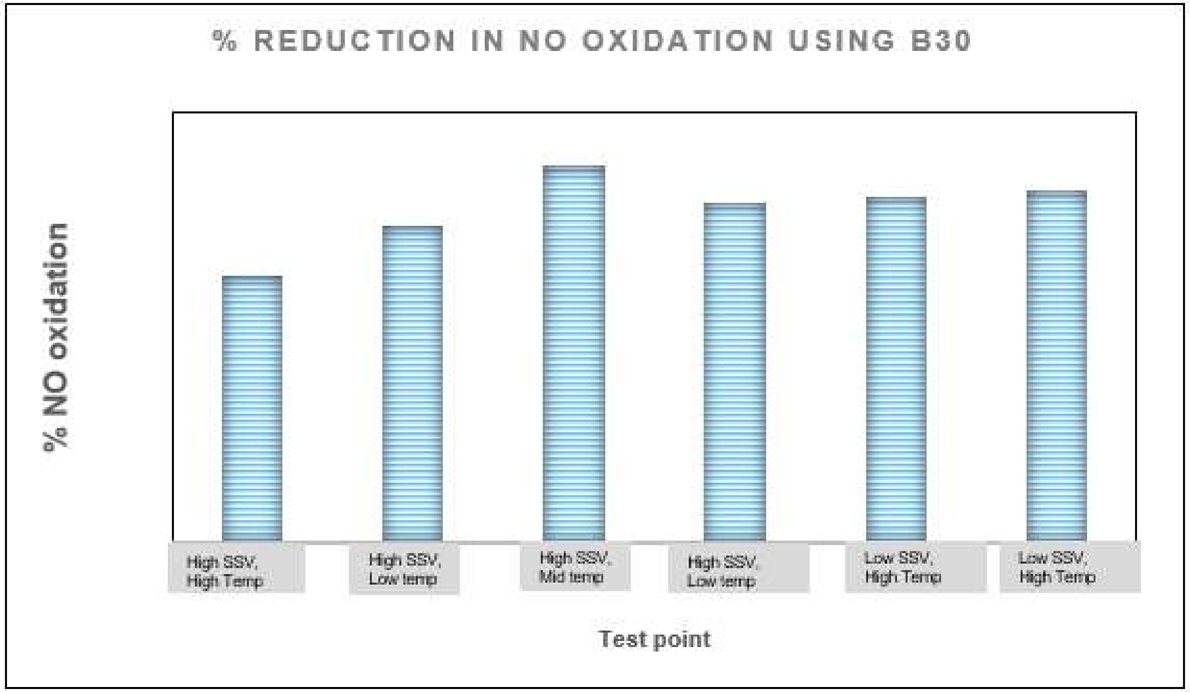
- K and Na are diffused into the washcoat layer, while P and Ca majorly accumulated on the surface of washcoat

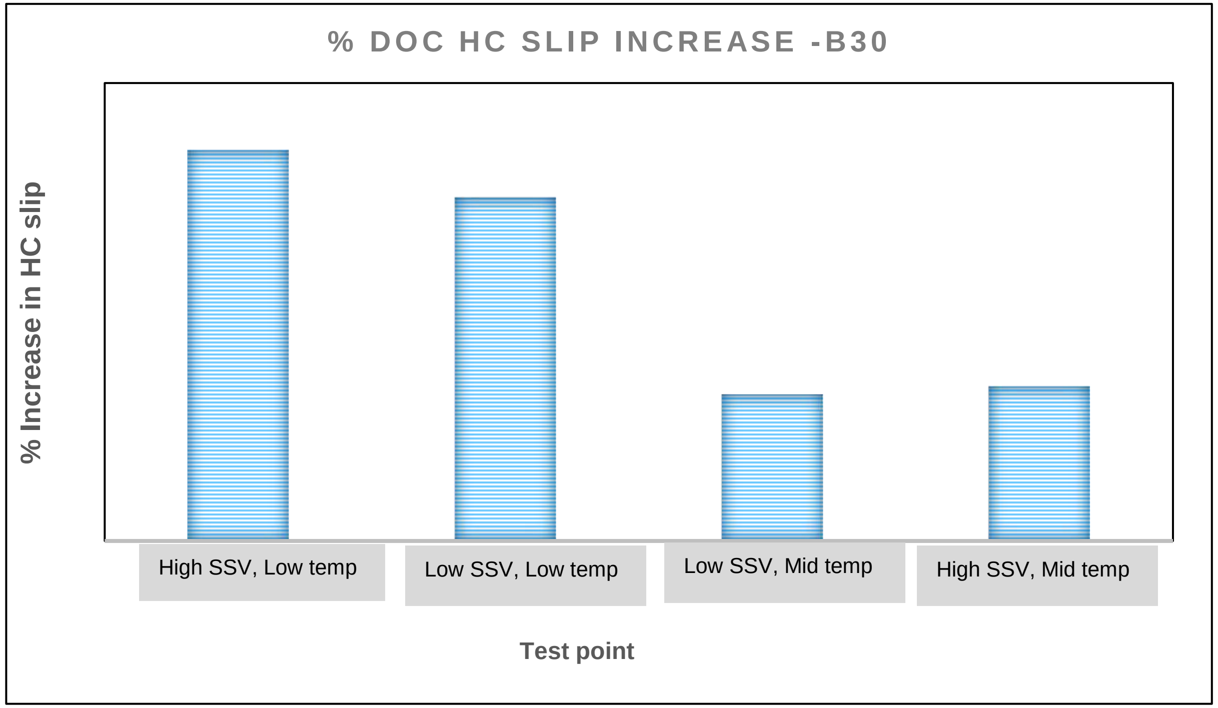


Figures from Williams et al (2013)

Impact on DOC (Continued)

- In-house testing was completed using Mid Range Cummins Engines
- Biodiesel included B30 blends
- Test Type: Accelerated Aging

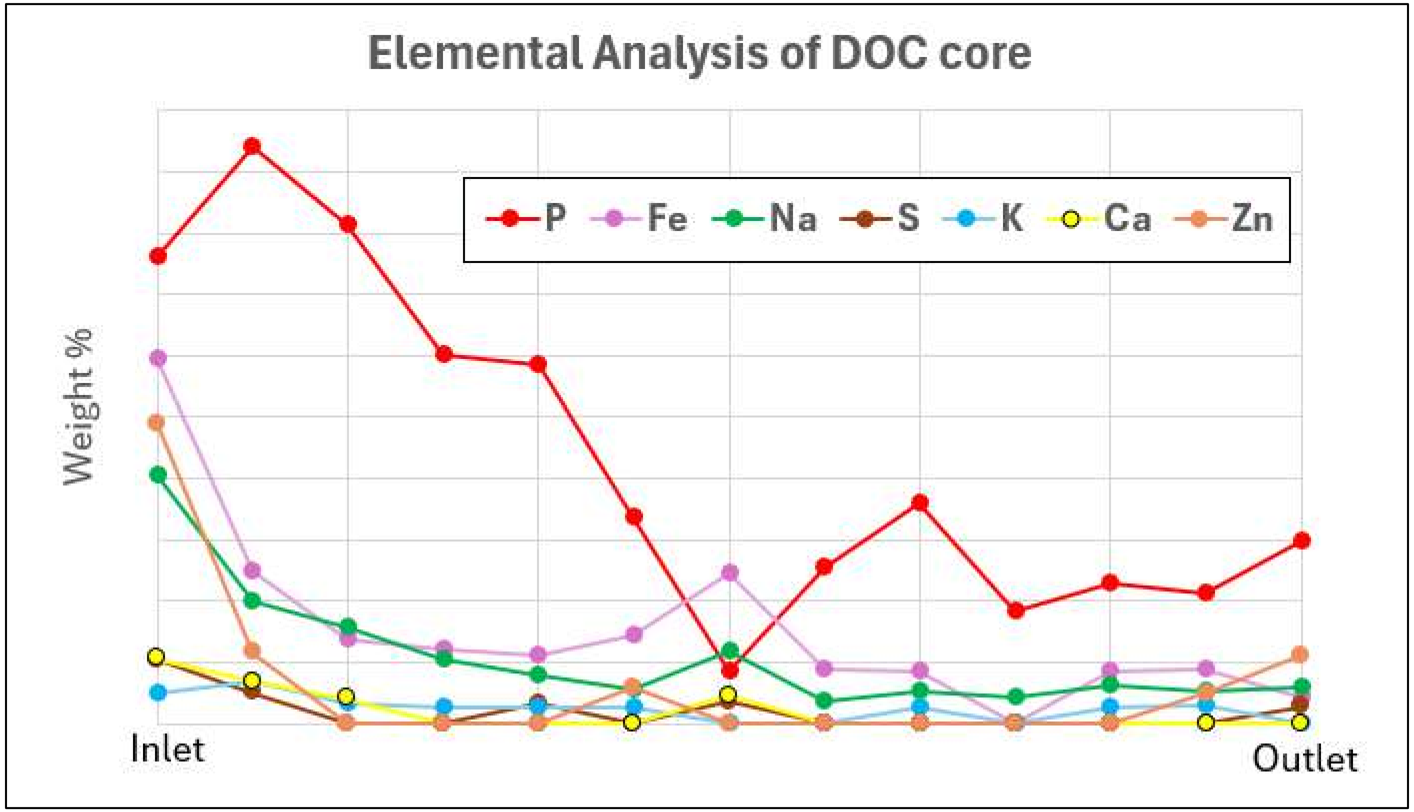


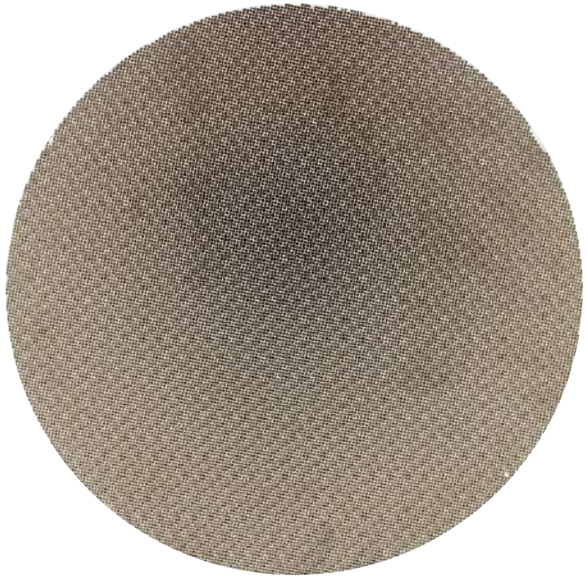


Key findings:

1. A shift in the light off to about 18% was observed compared to light off without diesel
2. Higher HC slip was observed only at low temperatures during the oxidation tests.
3. Lower NO Oxidation observed in high SSV

DOC





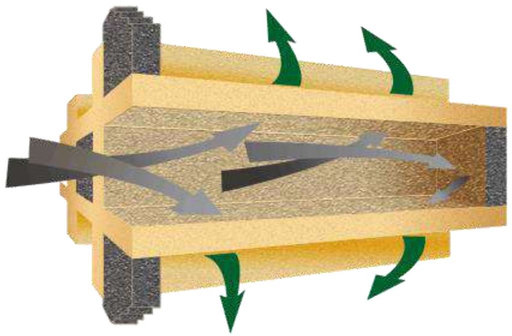
EDS analysis shows presence of various contaminants

- C- possible source – soot, Hydrocarbon .
- Fe- possible source - corrosion or erosion of upstream component.
- Na – Possible source could be Bio-diesel.
- Ca ,Zn and P - possible source - Lube oil.
- S- possible source – fuel.
- Si- possible source - Dust / dirt.

- Changes in performance of the DOC may be attributed to the presence of the contaminants from the biodiesel
- DOC inlet temperature is slightly higher for DPF to achieve regen target temperature

Impact on DPF performance

Reference: An experimental study of the role of biodiesel on the performance of diesel particulate filters



- DPF performance is a function of the pore structure, permeability, and properties of the soot.

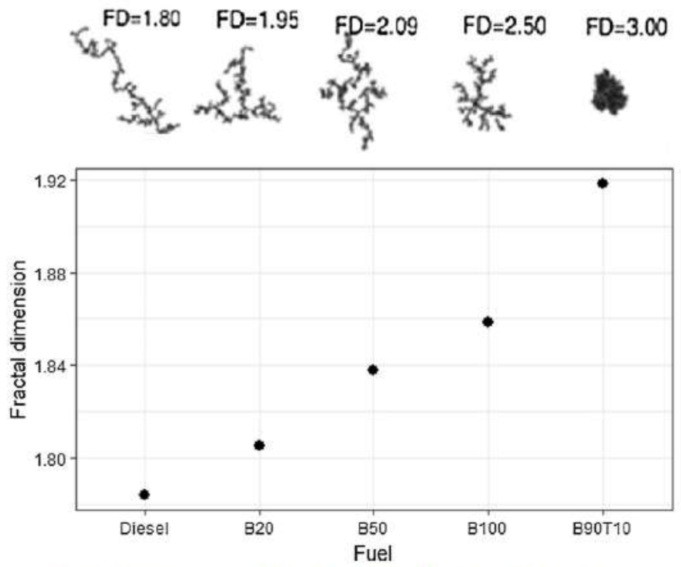


Fig. 7. Fractal dimension of the soot particles coming from the combustion of the fuels used.

Particle size impact on FE⬆

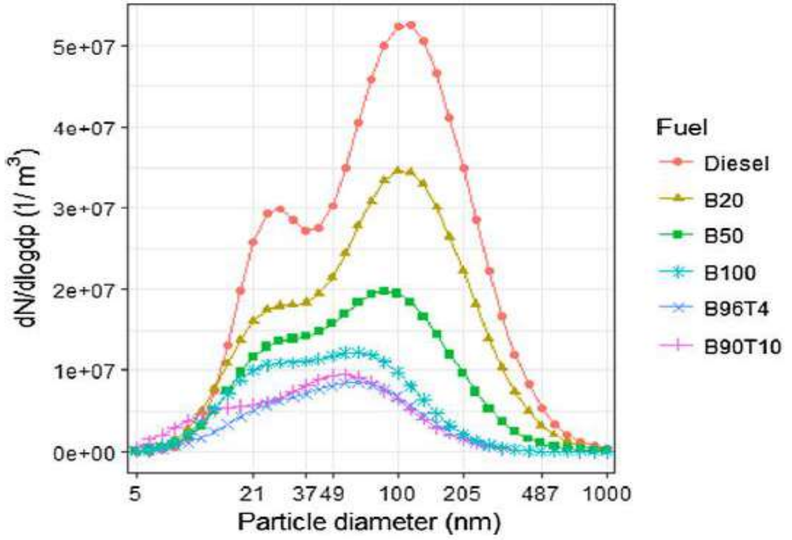
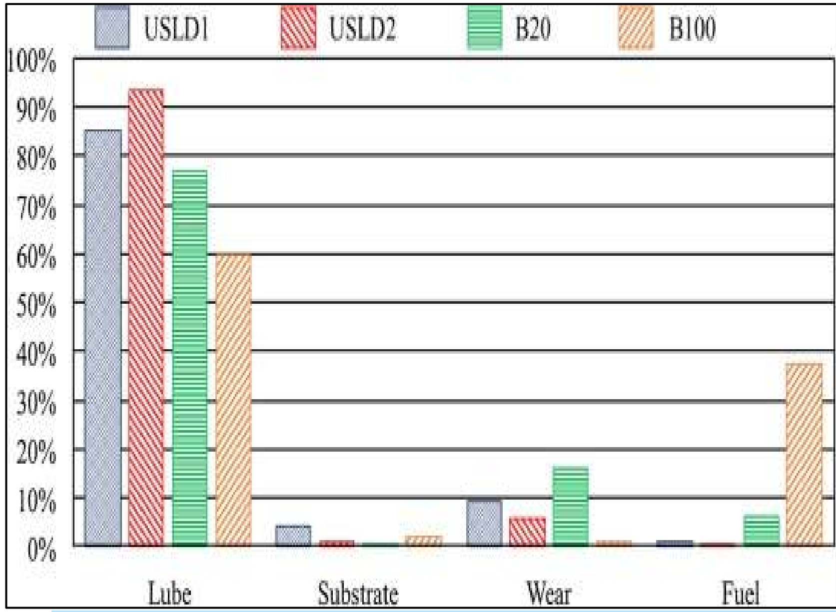


Fig. 3. Particle size distribution for the tested fuels.

Change in particle size distribution



Ash contribution from fuel is higher

Impact on SCR and ASC

Reference: Impact of Fuel Metal Impurities on the Durability of a Light-Duty Diesel Aftertreatment System, Williams et al (2013)

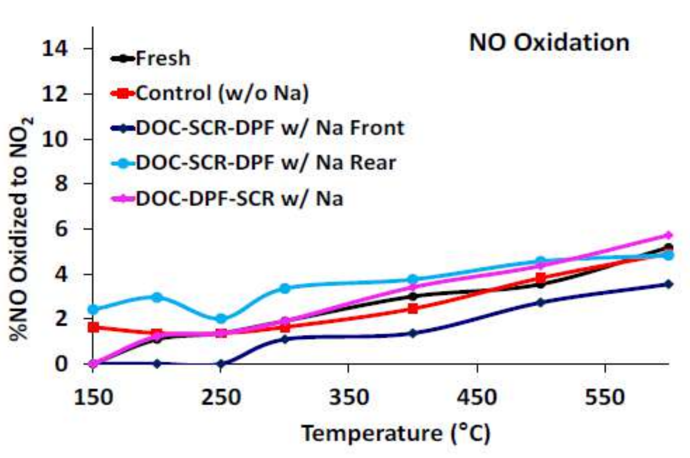


Figure 4.4.9 NO to NO_2 oxidation in fresh and accelerated Na-aged SCR catalysts.

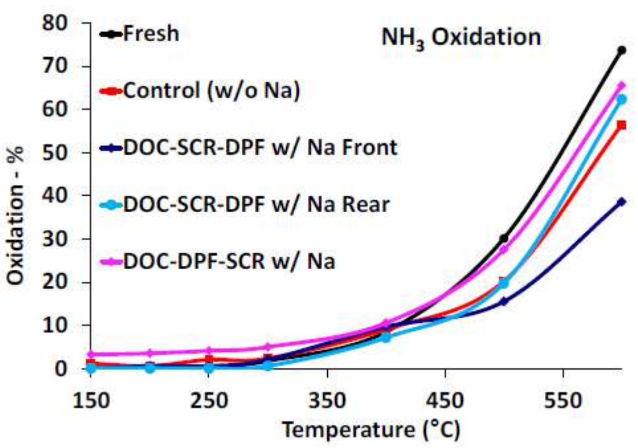


Figure 4.4.11 NH_3 oxidation in fresh and accelerated Na-aged SCR catalysts.

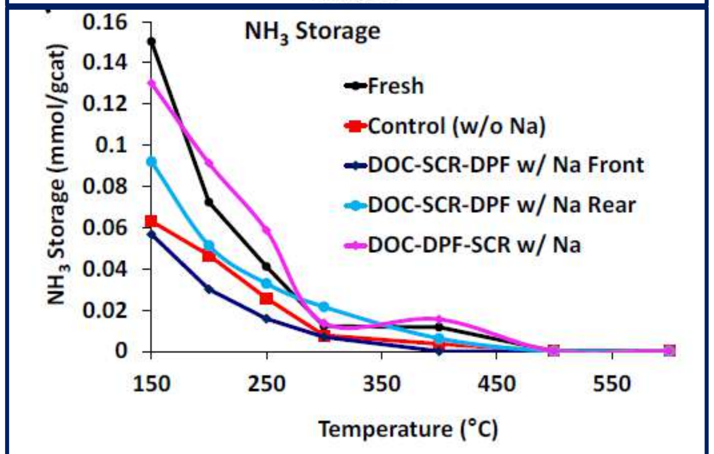


Figure 4.4.10 NH_3 storage capacity in fresh and accelerated Na-aged SCR catalysts.

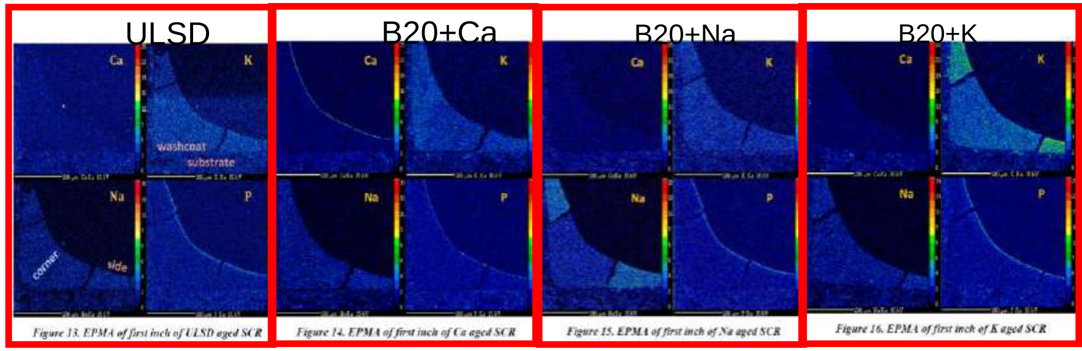
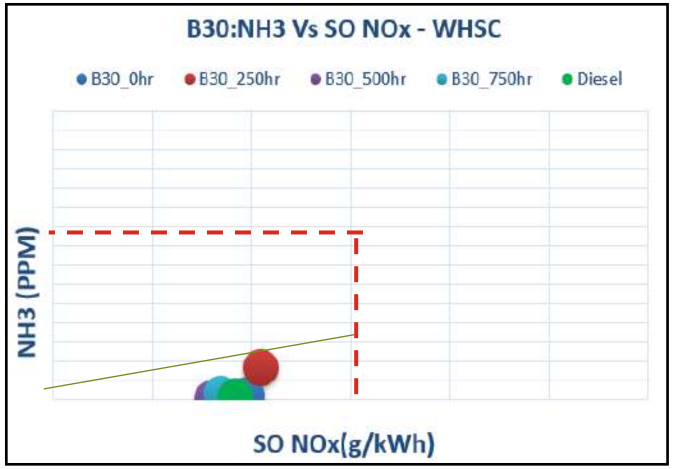


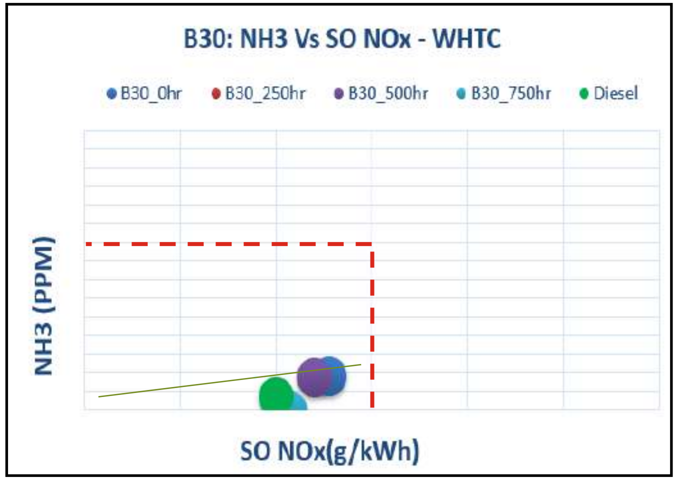
Figure 13. EPMA of first inch of ULSD aged SCR
Figure 14. EPMA of first inch of Ca aged SCR
Figure 15. EPMA of first inch of Na aged SCR
Figure 16. EPMA of first inch of K aged SCR

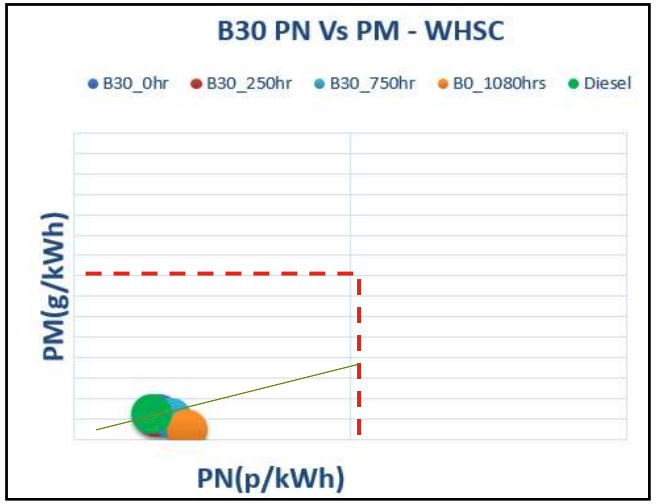
- K, Na, Ca and P are detected only at 1st inch of front SCR
- K and Na are migrated into washcoat
- Ca and P are accumulated on washcoat surface

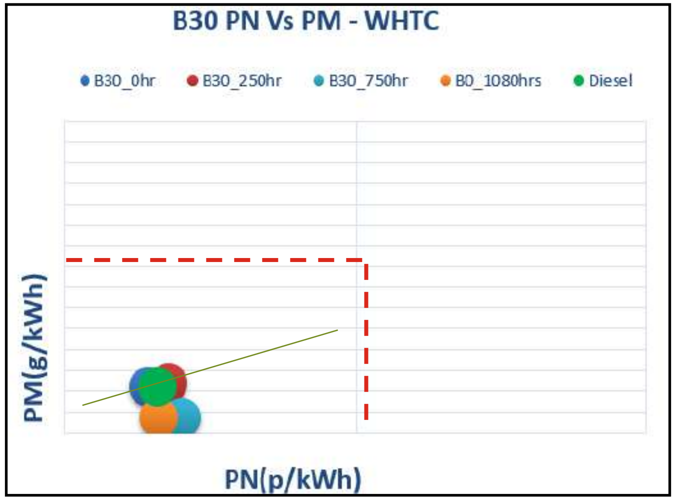
- SCR NO oxidation function didn't align with Na loading, indicating Na contamination isn't directly impacting NO oxidation function
- It appears that both Na contamination and thermal aging effects are contributing to reduction in NH3 storage capacity
- NH3 oxidation degraded after 450°C significantly and similar trend as the standard SCR function. This suggests that the performance loss associated with Na contamination could be related to a deactivation of and/or a reduction in the number of the Cu sites responsible for NH3 oxidation

System Interactions and emissions





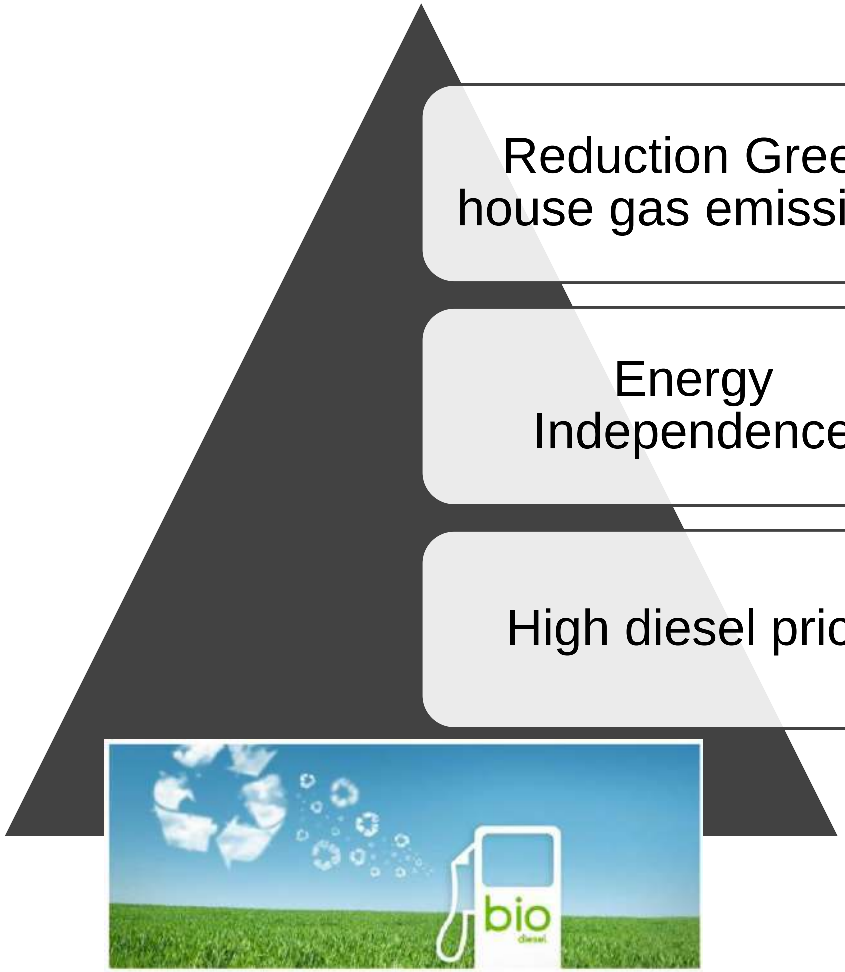




Key Findings

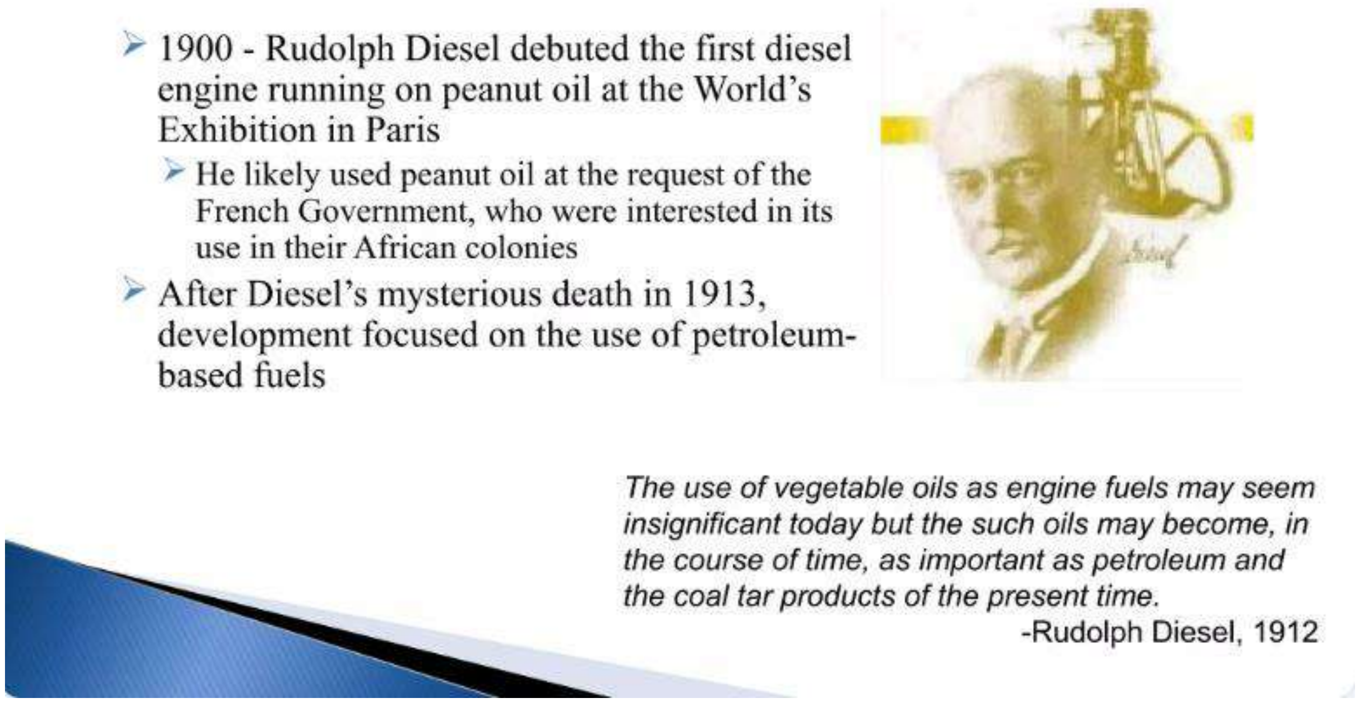
- With increase in time there is marginal increase in SO NOx and NH3, which is similar to the overall system level impact observed in literature with regards to impact on engine emissions
- System out particulate matter and particulate number did not show a significant increase with respect to increase in the number of hours of testing.
- Overall ash accumulation did not show any significant change compared to the ultra-low sulfur diesel fuel, and this may be attributed to the total hours of testing

Summary



- Literature suggest there are a lot of benefits of using the biodiesel blends in reduction of emissions
- Biodiesel production has increased globally due to the rising demands in fossil fuels
- The impact of biodiesel on emissions has been positive on decreasing critical green house gas pollutants
- Technologies may be further investigated to enhance performance of after treatment system catalysts at higher blends of biodiesel:
  - **Diesel oxidation catalyst:** Improved ratios of precious group metals to overcome the light off challenges?
  - **Diesel Particulate filters**: Improved ash hold capacity filters with enhanced filtration efficiency
  - **Selective Catalyst Reduction catalyst:** Enhanced low temperature conversion efficiencies

Q&A


1900 - Rudolph Diesel debuted the first diesel engine running on peanut oil at the World's Exhibition in Paris
He likely used peanut oil at the request of the French Government, who were interested in its use in their African colonies
After Diesel's mysterious death in 1913, development focused on the use of petroleum-based fuels
The use of vegetable oils as engine fuels may seem insignificant today but the such oils may become, in the course of time, as important as petroleum and the coal tar products of the present time.
-Rudolph Diesel, 1912