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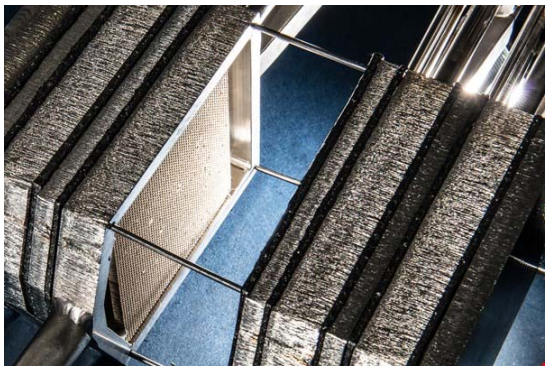
Elimination of Diesel Particulate Filters and SCR Equipment using a novel Catalytic Evaporation (CatVap®) Device to reduce Soot and NO_x emissions in Internal Combustion Engines



Robert Szolak, Dr. Achim Schaadt, Florian Rümmele, Fraunhofer ISE

Michael Mazzuca, T.F. Hudgins Inc.

Dr. Steven Gedeon, Behr Associates

23rd Annual MDEC Conference, Toronto Canada

October 03.2017 – 05.2017

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Fraunhofer-Gesellschaft

One of the largest organizations for applied research in Europe

- 69 institutes and research units
- 24,500 staff
- $2.5 billion total annual research budget.
- 20,000+ patent families (e.g. MP3…)
- CatVap Team from ISE, Freiburg
- Funded by Fraunhofer Venture and Innovator Programs in HQ

2014 THOMSON REUTERS TOP 100 GLOBAL INNOVATORS

mp3 DAB+ SiriusXM SATELLITE RADIO GALILEO

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Diesel Engines

Wide Range of Non- and Off Road Applications

- Advantages of Diesel Engines:
  - High Efficiency
  - Good Engine Characteristic → high torque and low speed

  → Best solution for Non-road applications
- Disadvantages:
  - Production of Harmful Emissions like NO_x- and Soot
  - Complex Exhaust Aftertreatment Systems to meet Tier 4 / Stage IV

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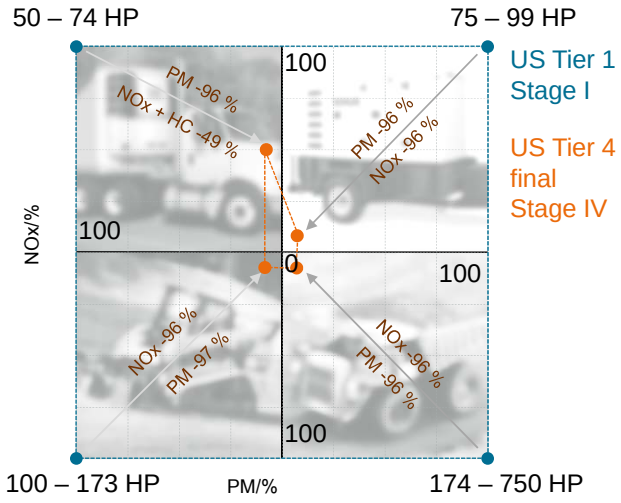
Challenges for Diesel Engines

Emissions Reduction to meet Tier 4 / Stage IV

- Soot and NO_x-reduction based on Tier 1 / Stage I
- 75 – 750 HP
  - ↓ NOx: 96 – 97%
  - ↓ PM: 96 % (Particle Number under discussion)
- 50 – 75 HP, only NOx and HC regulation
  - ↓ PM: 96 %
- Complex Exhaust Aftertreatment Systems



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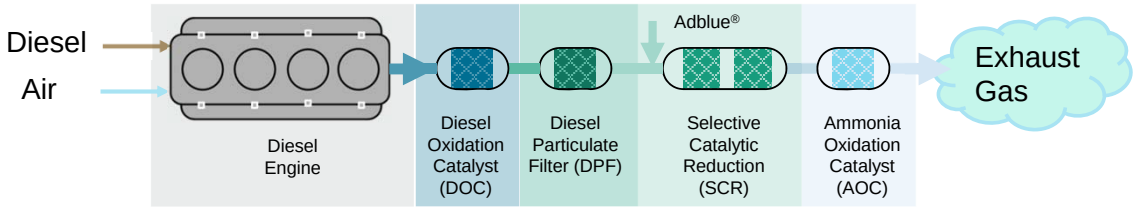
Tier 4 final Diesel Engine

Complex Exhaust Aftertreatment



- ↑ Fuel Consumption (↑ CO_2-Emissions)
- Lower Performance
- NOx removal from diesel exhaust gas
  - Adblue injection required (2nd lubricant)
  - Low exhaust temperature → polymerization

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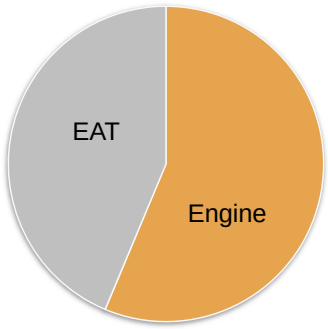
Volume Diesel Engine with Exhaust Aftertreatment for Non-road applications

Tier 4 final

Caterpillar C4.4 ACERT™ Tier 4 for 173 bhp (130 kW)

- Volume Diesel Engine incl. Exhaust Aftertreatment (EAT) System



- EAT > 40% of the engine
- Major Part EAT → NO_x-removal (SCR-System, Adblue Tank not included)

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Cost of Emission Reduction Technologies
Exhaust Aftertreatment System for Non-road Applications

Nett Technologies INC.: BlueMAX™ PLUS 100 SCR system (Retrofit)

Picture: www.drawinghub.com

- Estimated costs for added emissions controls equipment approx. 1-3% of total equipment price
  - Approx. 1-3% of total equipment price, e.g. total price bulldozer 175 hp: $230,000 → $6,900 for emissions control equipment+
  - Aftertreatment systems (DOC, DPF, SCR) incl. sensors, Adblue tank, etc.): approx. $7,000#

F. Posada et. al, Cost of Emission Reduction Technolgies for Heavy-Duty Diesel Vehicles, icct (the internationl council on cleam transportation), Feb. 2016

+ https://www.dieselnet.com/standards/us/nonroad.php

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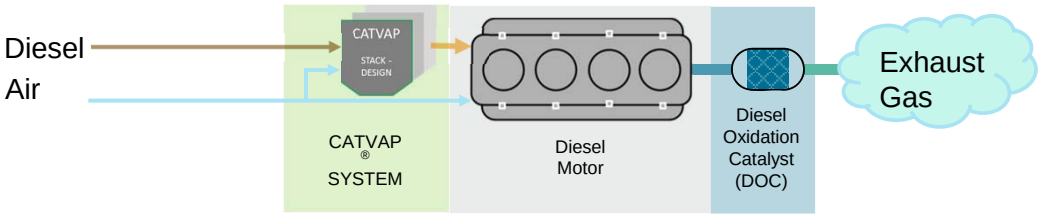
CATVAP®-Catalytic Evporation Process
New Approach for Low Emissions reduces Exhaust Aftertreatment System



- Fuel Vapor in the intake manifold (homogeneous mixing with air)
- In-cylinder NOx and Soot Reduction in Diesel Engines
- No SCR, DPF required

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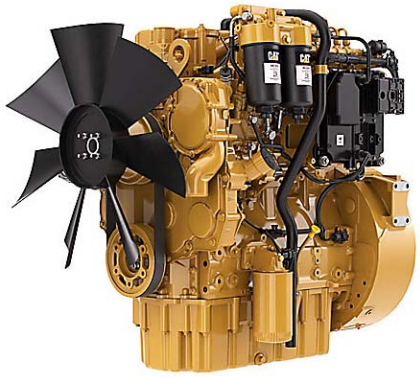
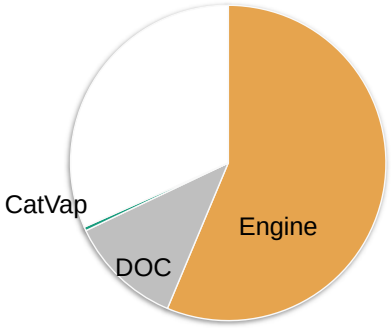
Volume Diesel Engine with CatVap®

Tier 4 final

- CatVap reduces EAT volume by 73%





- Only DOC required
- Volume CatVap for 173 HP → approx. 2 Liters

Caterpillar C4.4 ACERT™ (173 bhp, 130 kW)

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CatVap®

New Fuel Vapourization Technology for ICE

- Usable for a wide range of different fuels (diesel, kerosene, gasoline, biodiesel, PtL-fuels and blends…)
- Use in diesel engines: in-cylinder emissions reductions
- Use in gasoline engines: boost the octane number to increase efficiency/performance

Photo: CatVap® in Stack Design

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CatVap® – Technology

Compact Design and scalable for different applications

- Fuel modification by catalytic and cracking reactions
  - Fuel tailoring (change of ignition properties)
- Compact design
- Approx. 2 Liter reactor volume for 173 HP
- Scalable for small to large engines

Foto: CATVAP im Stack Design

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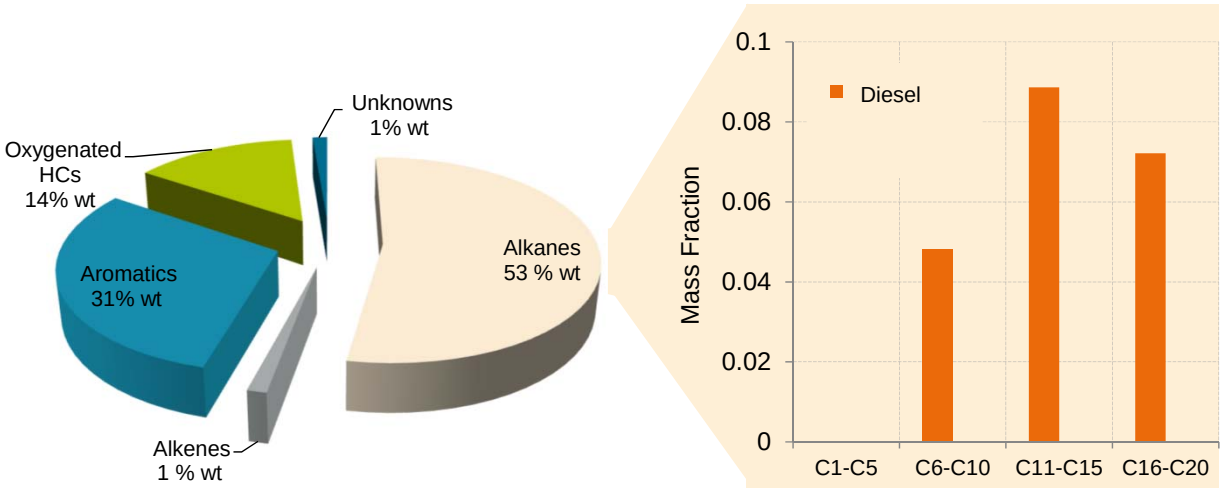
Diesel fuel DIN 590

Fuel Composition



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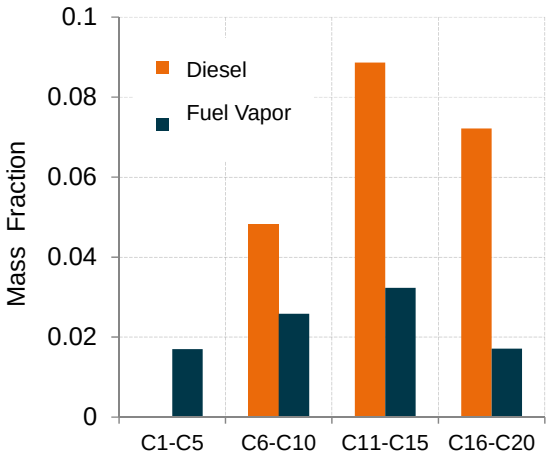
Fuel Tailoring by Catalytic Evaporation Process

Comparison of Alkanes in Diesel Fuel and CatVap® Fuel Vapor

- Strong reduction of heavy alkanes
- Significant increase of gaseous alkanes (CH_4, C_2H_6, C_3H_8)
- Further shift of fuel composition, not shown in the diagram:
  - Production of gaseous alkenes (C_2H_4, C_3H_6)
  - Shift of aromatics (from the heavy aromatics to the lighter ones)



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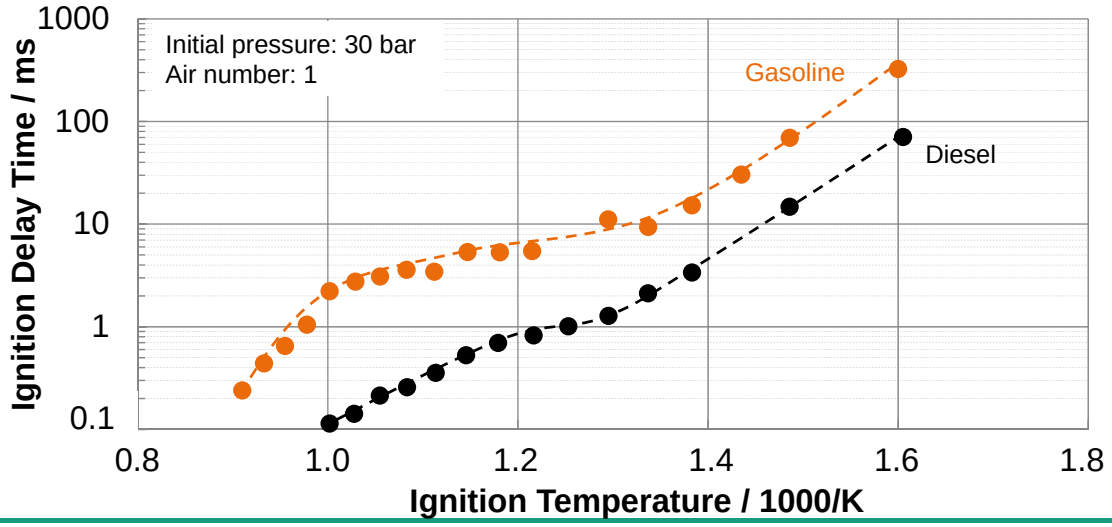
Ignition Properties of Gasoline and Diesel

Ignition Delay Time depends on Ignition Temperature



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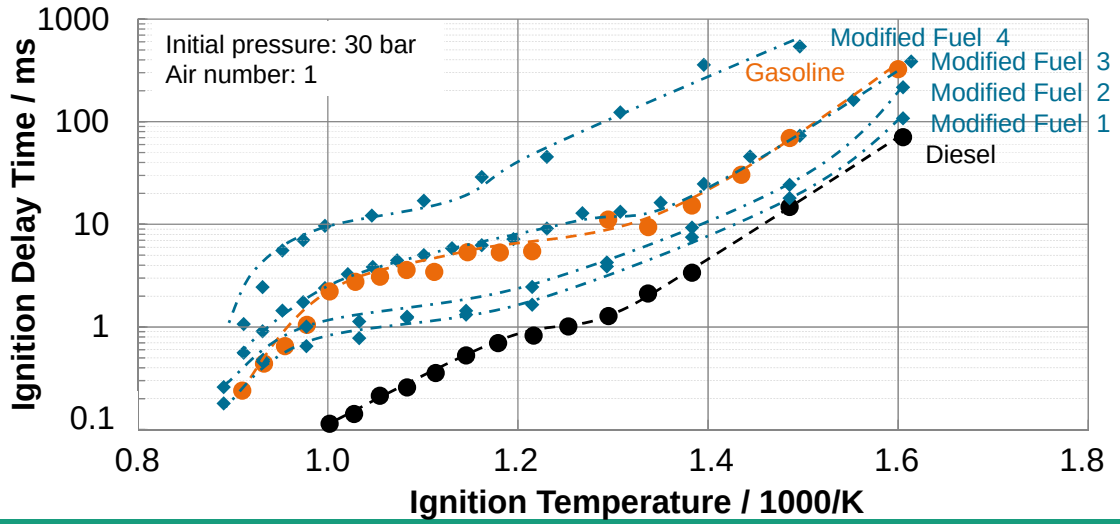
Variable Adjustment of the Ignition Properties possible



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CatVap® Engine Test

Test Platform at Fraunhofer

Engine Tested	1 Cyl. Heavy Duty Engine
Displaced Volume	1800 ccm
Compression ratio	15.5:1
EGR (external)	0…30%
Common-Rail System	2200 bar
Rated Engine Speed	2000 rpm
Turbocharging (external)	max. 2.2 bar (abs.)

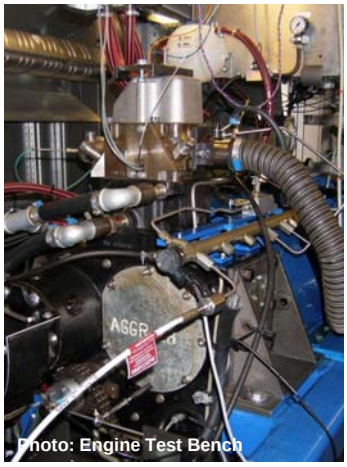

Photo: Engine Test Bench

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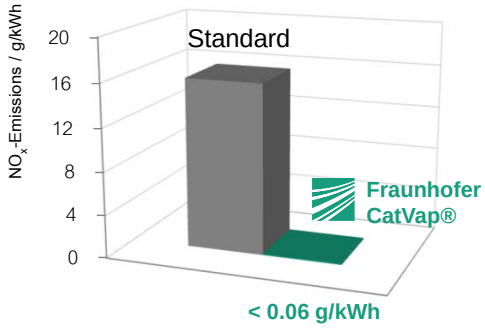
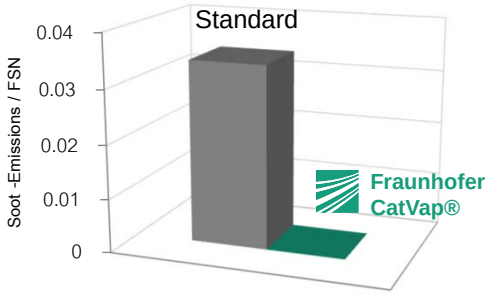
CatVap® Engine Tests

Dramatic Emissions Reduction in Diesel Engines with Fraunhofer CatVap Technology without Exhaust After-Treatment System

- NO_x-Emissions
- Soot Emissions





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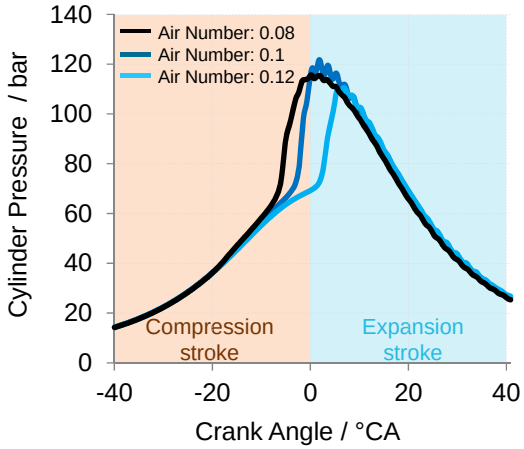
Influence of CatVap® Operating Parameters on Combustion Phasing

Engine Tests without Exhaust Recirculation

- Operation with fuel vapor only
- Charge air pressure = 1500 mbar
- Diesel flow rate constant
- Shift of the Combustion Phase by changing the air flow (Air Number)
- Shift from -5.3 °CA to +3.8 °CA
- Increase of Efficiency
- ↑ IMEP: 6 bar → 6.8 bar



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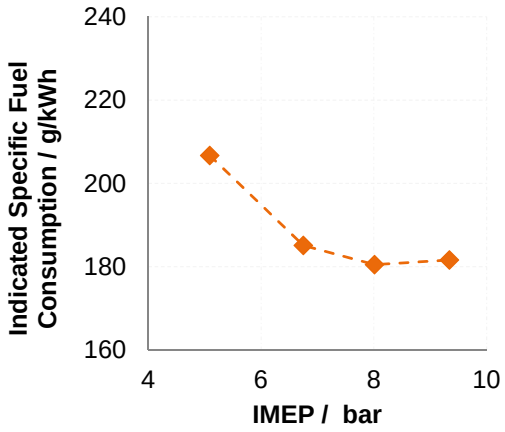
Fuel Consumption CatVap® Engine Test:

Indicated Specific Fuel Consumption

- Operation with fuel vapor only
- ↓ Fuel Consumption with ↑ IMEP
- Fuel Consumption at best point 180 g/kWh
- Ultra low NOx-emissions and low fuel consumption
- Further increase of efficiency possible



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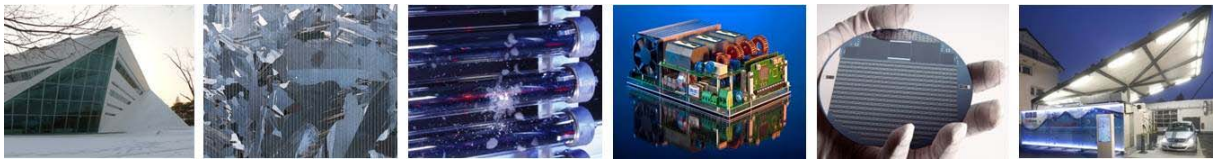
Thank you for your attention!



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