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Inspiring science, enhancing life

"Cleaner IC Engines for Sustainable Environment With Innovative Emission Control Technologies (ECT 2019)"

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Emission Control for Gensets

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Stationary emissions control (SEC) for combustion sources

Waste-to-Energy Plants

Coal Power Plants

Gas Turbines

Locomotives

Marine Engines

Digester Gas

Diesel / Gas Generators

Gas Drilling & Compression

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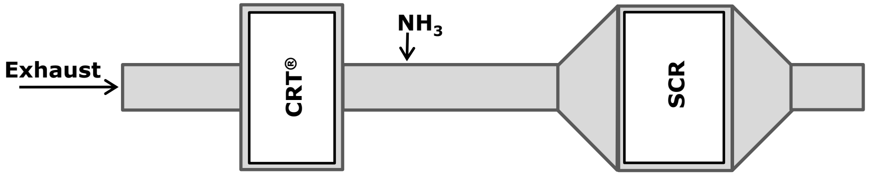
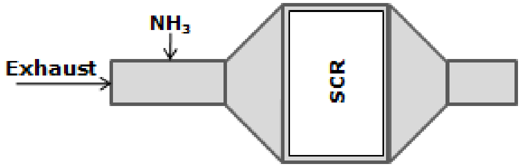
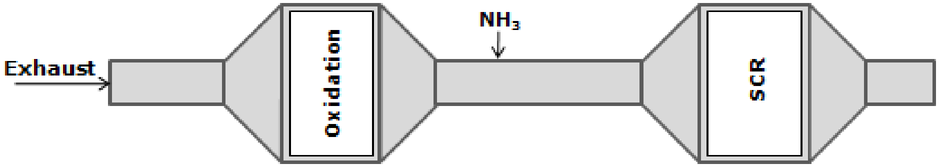
Catalyst systems tailored to performance requirements



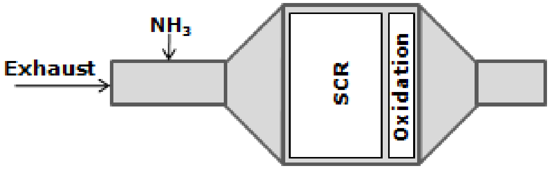
- CRT®+SCR for control of diesel PM, NOx, CO and HC



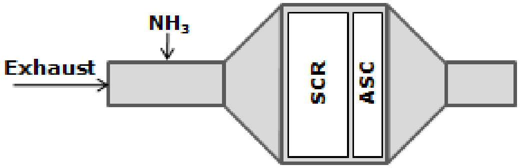
- High NOx reduction over SCR
- No CO reduction



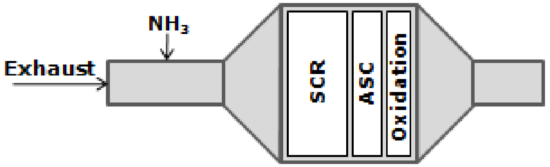
- Oxidation catalyst for CO reduction
- Upstream of SCR requires separate housing



- Oxidation catalyst downstream of SCR oxidizes NH_3 slip back to NOx, can also form NO_2
- Requires large SCR volume



- Compact SCR+ASC for high NOx reduction
- Also achieves CO, HC conversions



- ASC converts NH_3 slip to N_2 allowing compact SCR+ASC+DOC design
- Very high NOx, CO, HC conversions

SCR and catalyst sizing/design

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SCR uses NH_3 as the reductant to remove NOx from lean exhaust

Chemical reactions relevant to SCR in lean (excess O_2) exhaust streams:

$4\ NH_3 + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O$	*standard SCR reaction (fast)*
$4\ NH_3 + 2\ NO_2 + 2\ NO \rightarrow 4\ N_2 + 6\ H_2O$	*fast SCR (very fast)*
$4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$	*undesired reaction (above 425°C)*

note: there are other reaction pathways but the above reactions are dominant in lean exhaust

Reaction stoichiometry: one molecule NH_3 reacts with one molecule of NOx

$SO_2 + ½\ O_2 \rightarrow SO_3$	*oxidation of sulfur*
$NH_3 + SO_3 + H_2O \rightarrow NH_4HSO_4$	*formation of ammonium bisulfate, fouls catalyst and equipment*

These reactions are not usually a concern for ULSD and NG engines

Urea often used as NH_3 source because it is easier to handle/store than NH_3

One molecule of urea decomposes into two moles of NH_3: $\underset{\textit{urea}}{(NH_2)_2CO} + H_2O \rightarrow 2\ NH_3 + CO_2$

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SCR relies on NH_3 reductant which is also regulated

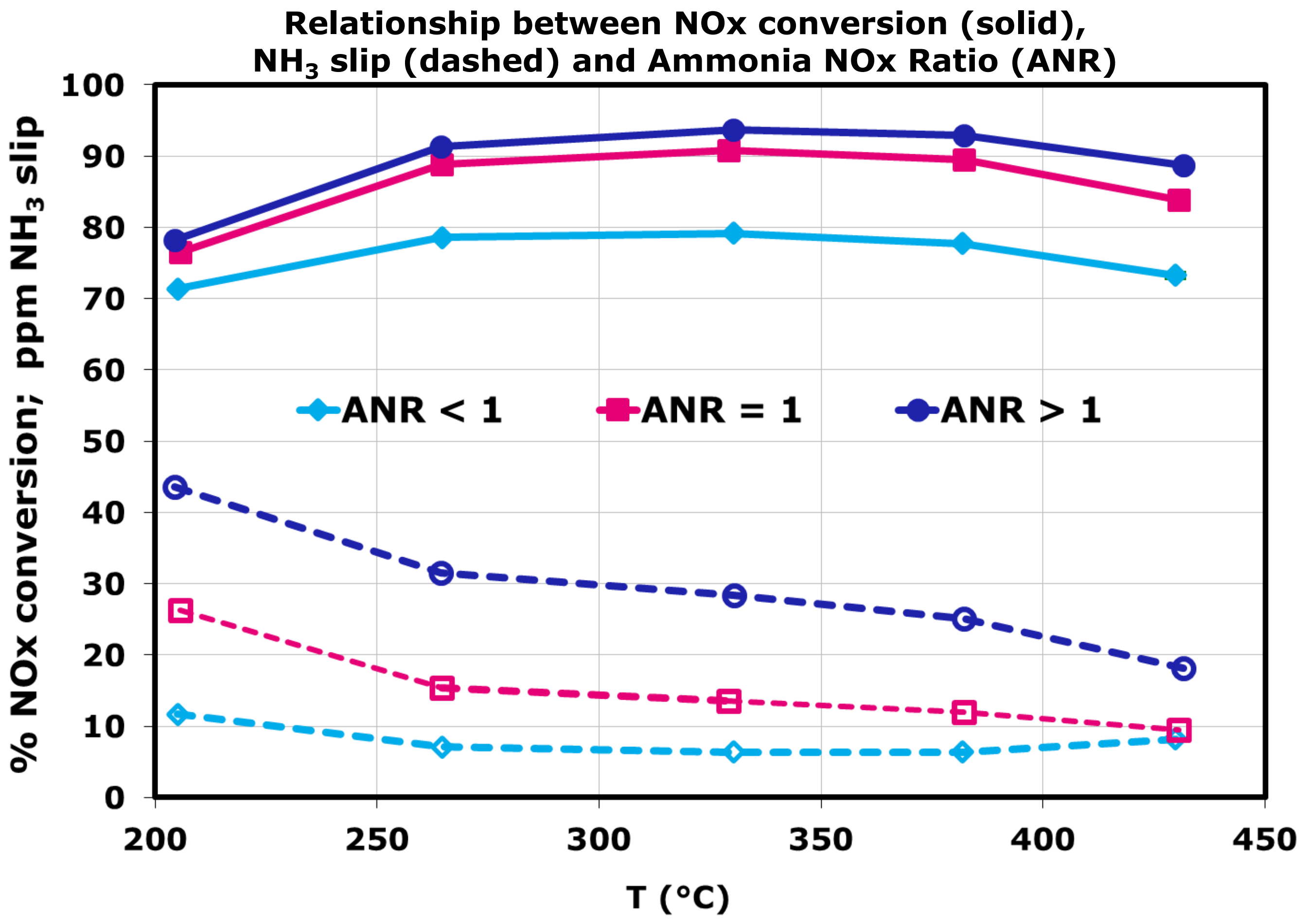
Catalyst sizing and operating parameters are critical

ANR < 1
Low NH_3 slip,
Low NOx conversion

ANR > 1
High NOx conversion,
High NH_3 slip

At ANR = 1.0
100% conversion, zero slip possible with:

- large catalyst volume
- perfect mixing, flow distribution



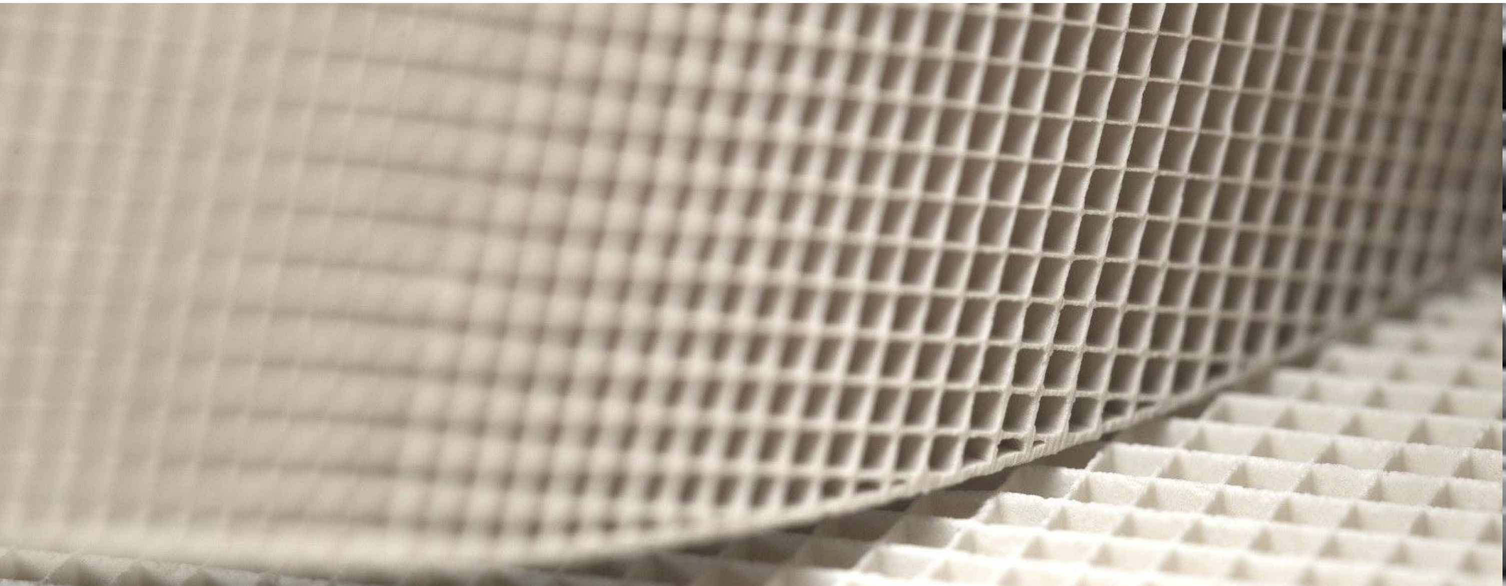
Oxidation catalysts

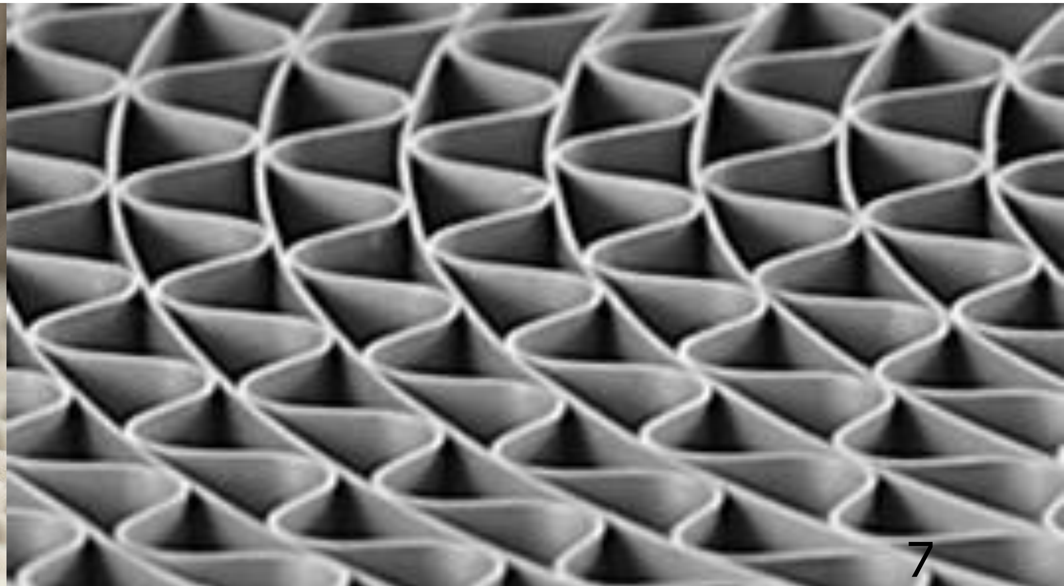
Oxidation catalysts (2-way)

also referred to as DOC (Diesel Oxidation Catalysts)

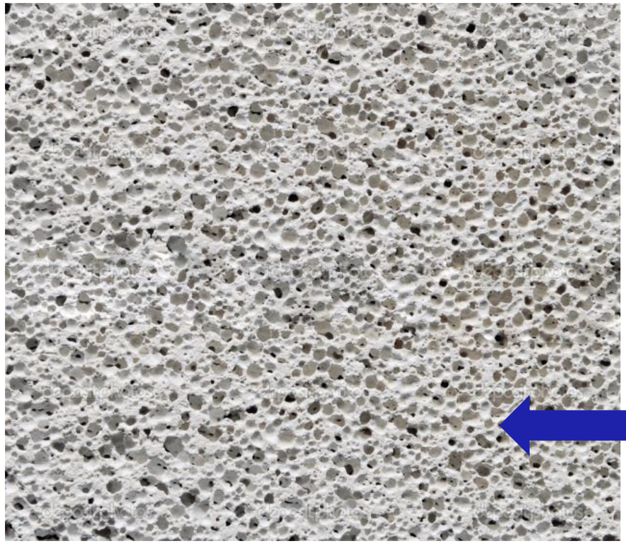
TWC (3-way)

Simultaneous conversion of HC, CO and NOx under stoic/rich burn operation



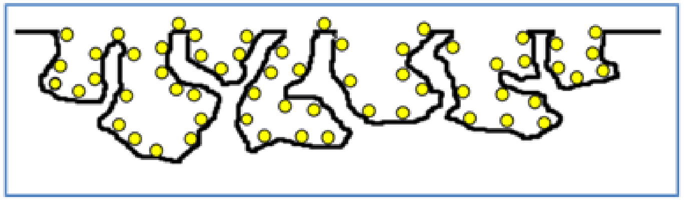


Flow-through emission control catalysts

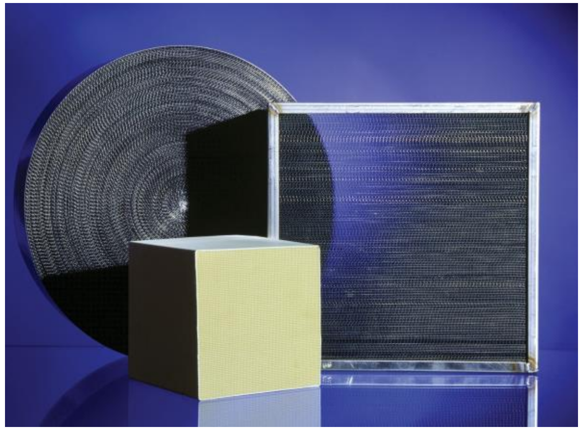


- To maximize surface area, particles are highly dispersed on high surface area supports

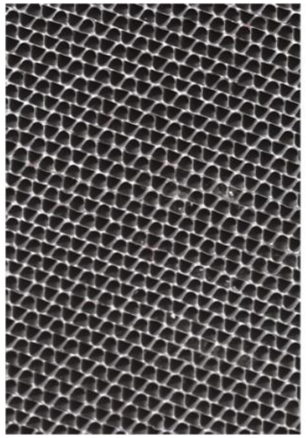
- Much like a sponge, the majority of the catalytic surface area exists in pores and channels

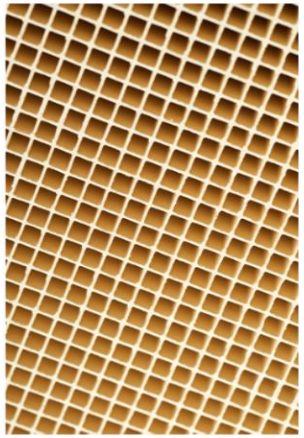


Catalytic material is coated onto metallic and ceramic substrates to produce flow-through emission control catalysts



Metallic and ceramic substrates





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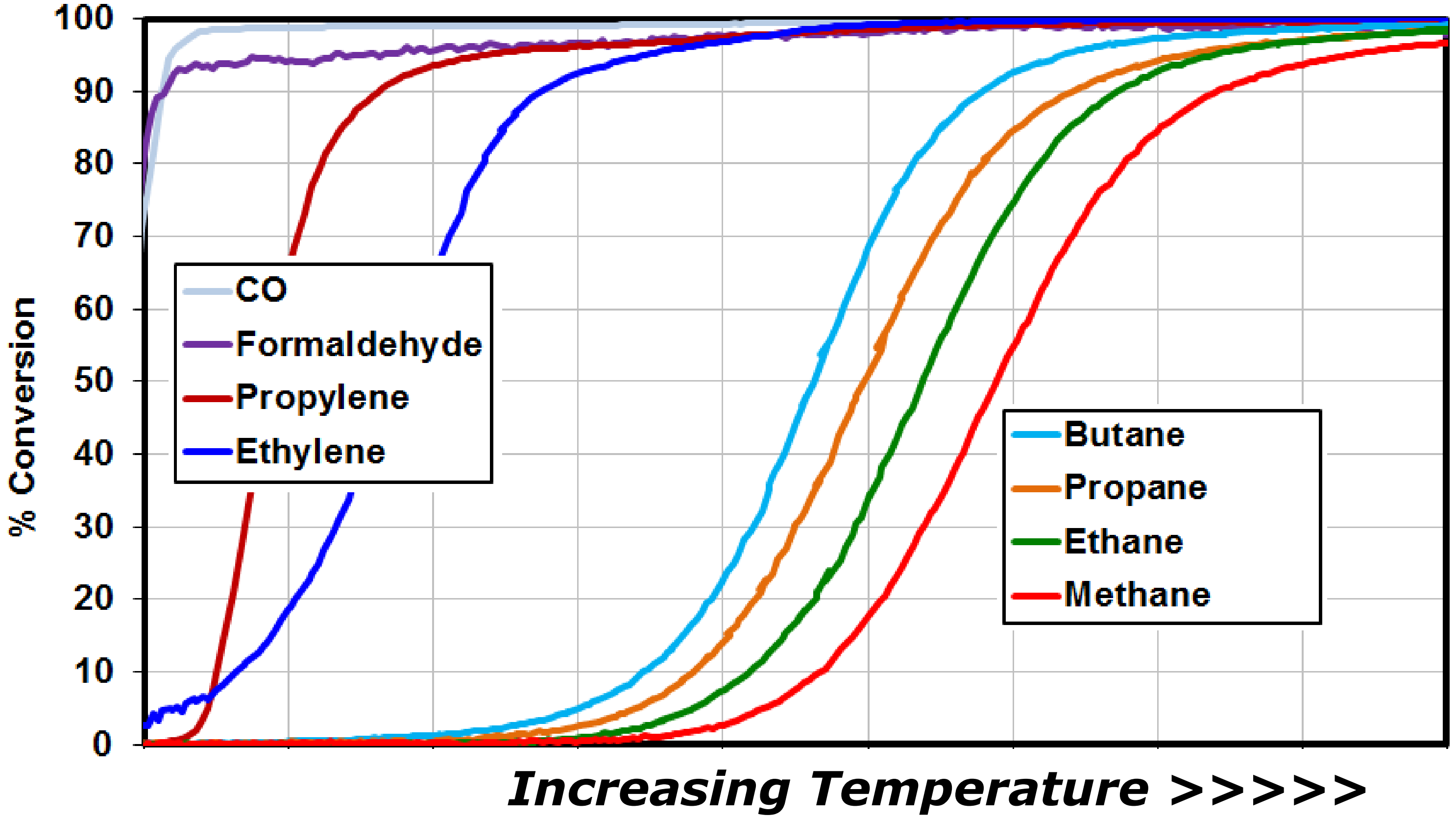
Oxidation catalysts (Pt, Pd, base-metals)

Lean exhaust (engines, turbines, industrial processes)

CO, VOC, HC conversions

$$CO + ½ O_2 \rightarrow CO_2$$
$$HC/VOC + O_2 \rightarrow CO_2 + H_2O$$



Highly stable molecules such as methane, ethane, propane and butane require high temperature to light off

Less stable, reactive molecules such as CO, formaldehyde, ethylene and propylene light off a much lower temperatures

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Catalyst deactivation modes

mechanism	description
poisoning	strong chemisorption of species on catalytic sites, sites blocked for catalytic reaction
fouling, masking	physical deposition of species on the catalytic sites and in pores of catalyst blocking the sites
thermal	loss of catalytic surface area, support area and catalyst-support interactions
vapor formation	reaction of gas phase component with catalyst material to produce volatile compound
attrition	loss of catalytic material via abrasion, mechanical disruption of the catalyst structure

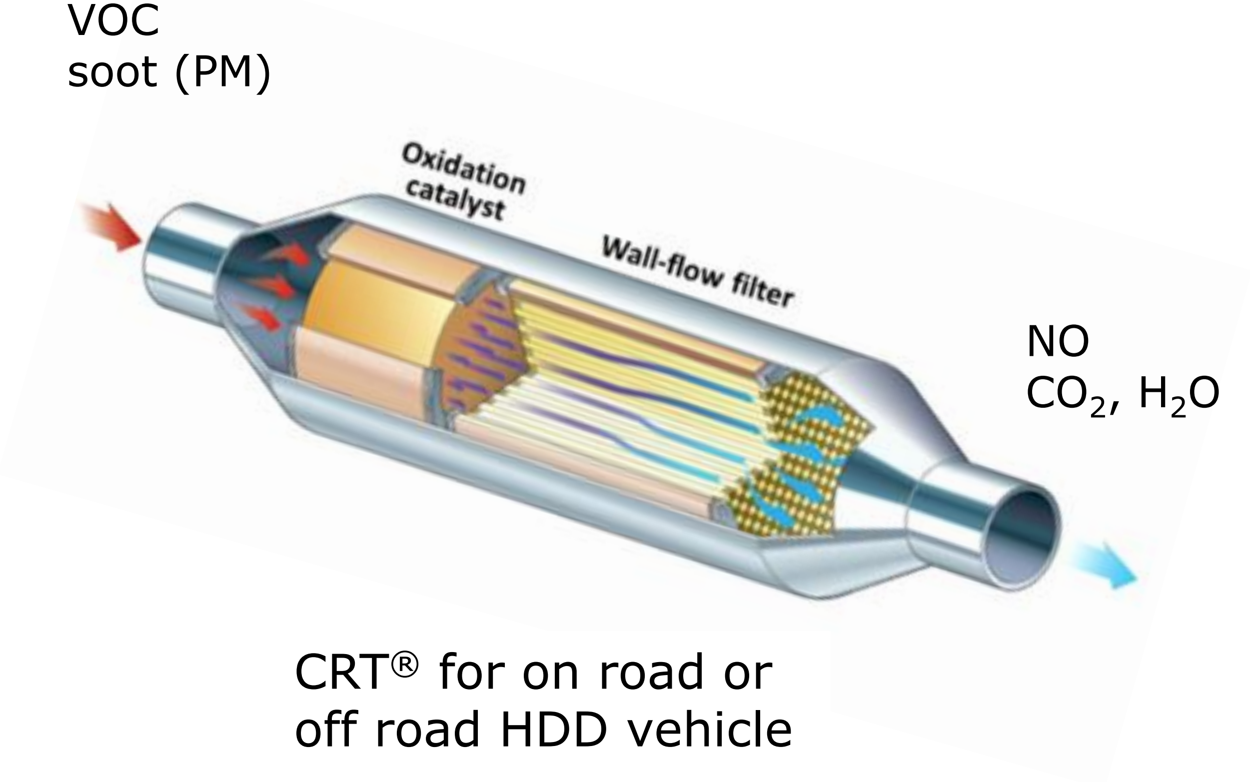
most relevant for NG, diesel engines and NG turbines

CRT®/DPF system review

Continuously Regenerating Trap (CRT®) technology

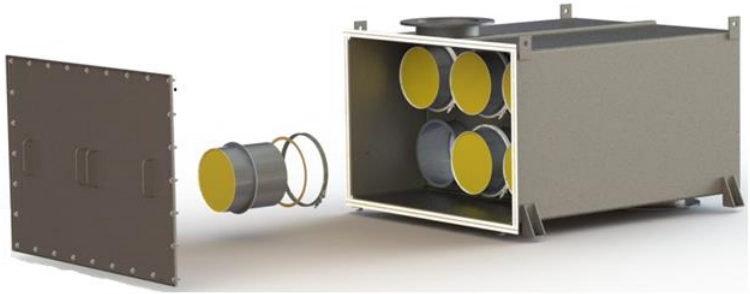
Diesel particulate filter (DPF) technology to control diesel particulate matter (PM), CO, HC

Diesel exhaust:
NOx (mostly NO)
CO
VOC
soot (PM)



NO
CO_2, H_2O

CRT® for on road or off road HDD vehicle



CRT® system installed on emergency backup genset

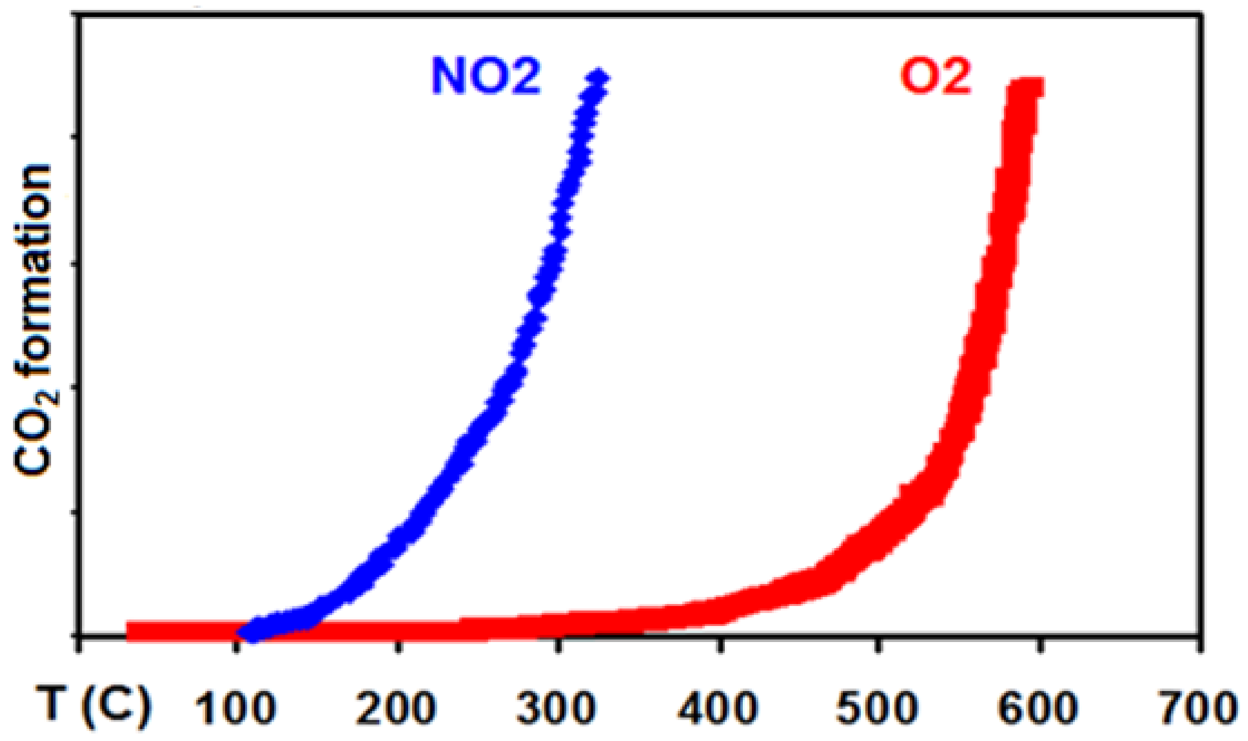
CRT® technology (Continuously Regenerating Trap)

- Operating principles: filtration + passive regeneration
- Wall-flow filter:
  - Channels open on inlet side are closed on outlet side
  - Exhaust is forced through walls
  - PM is trapped in the walls

Low profile CRT-2 for stationary engine

DPF inlet side is coated with soot, outlet side is clean

Temperatures at which NO_2 and O_2 react with soot



Typical diesel engine temperatures are not high enough for O_2 in the exhaust to react with soot and regenerate the filter

NO_2 reacts with soot at much lower temperatures

Majority of engine NOx typically composed of NO, not NO_2

NO does not react with soot

Oxidation catalyst used with filter to achieve passive regen at lower temps

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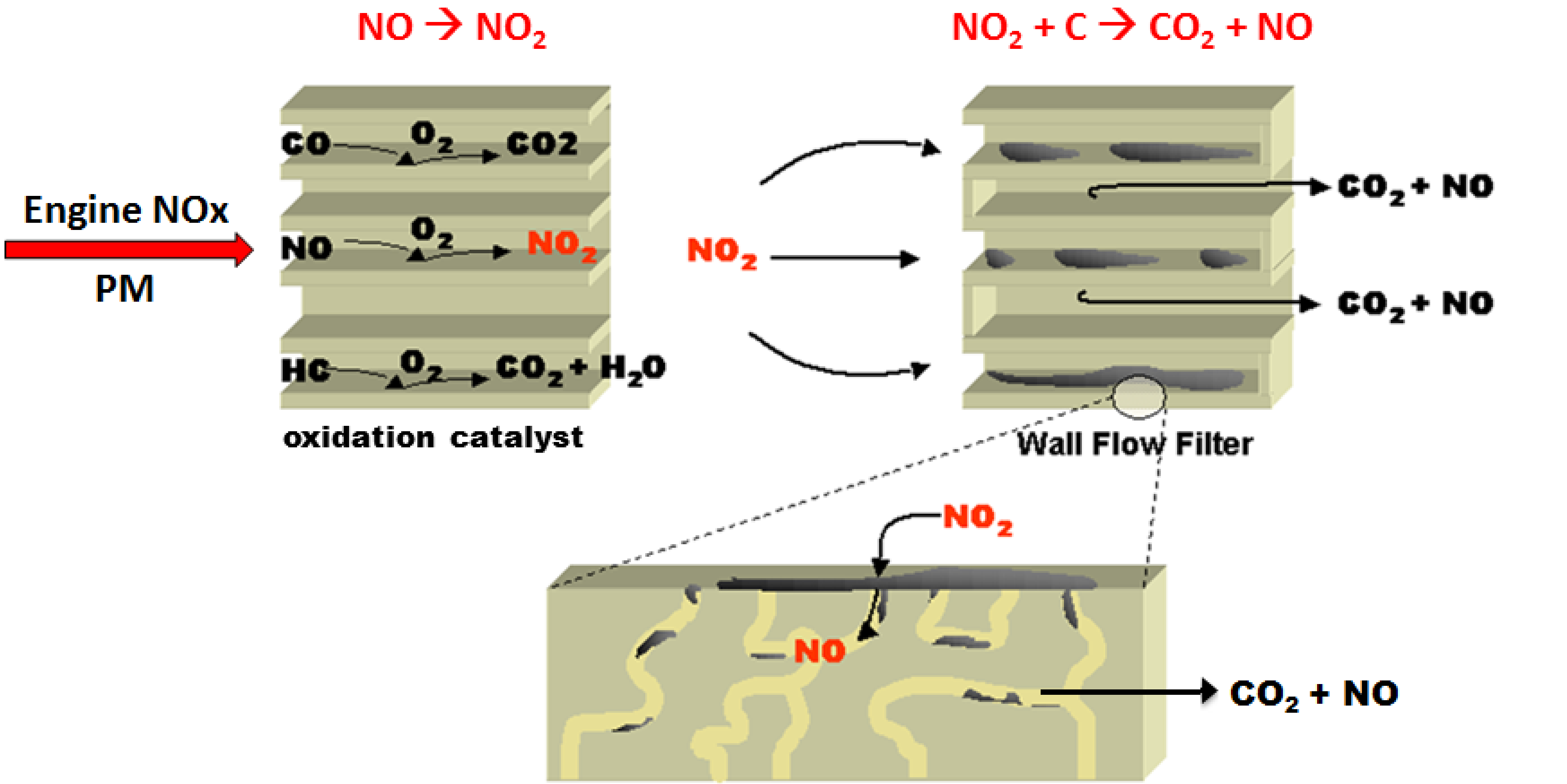
CRT® technology: Passive regeneration

Regeneration: rate of soot consumption > rate at which soot enters the filter

Critical reactions are NO to NO_2 over the DOC and NO_2 + soot in the filter



Passive regeneration dependent upon both temperature and NOx:PM

Temperature – as with any chemical reaction, temperature must be sufficient for reaction

- Lab reactor studies show NO_2+ soot begins ≈ 300°C

NOx:PM Ratio - must also be high enough for passive regeneration to occur

- PM in exhaust continually enters filter and is trapped in walls
- Sufficient NOx must be present so that rate of soot consumption exceeds the rate at which soot enters the filter

Challenges of using a DPF/CRT® on backup gensets:

- No defined duty cycle
  - Back-up gensets are only used periodically (i.e. power outage)
  - Gensets are "exercised" at idle or low load
    - Idle/low load exhaust temperatures and NOx:PM ratio are too low for passive regen

If passive regen does not occur, filter can plug with soot resulting in excessive backpressure on engine

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Effect of sulfur on CRT® operation

Diesel fuels contain sulfur compounds

During combustion, the sulfur is oxidized to SO_2, and some fraction to SO_3

SO_3 is a catalyst poison

- If DOC is poisoned the NO → NO_2 reaction will be inhibited resulting in insufficient NO_2 to consume the soot in the filter

In the presence of water: $SO_3 \rightarrow H_2SO_4$ (sulfuric acid)

- H_2SO_4 will adsorb to the soot, **adding to its mass**
- Typical conversion requirement 85% mass

Fuel sulfur level is critical desired PM reduction

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World Leader in Emission Control Technologies

Mobile on-highway, off road, heavy duty (HHP) and stationary (including locomotive and marine)